SELF-EFFICACY, SELF-REGULATION, AND PHYSICAL ACTIVITY BEHAVIOR IN TYPE 2 DIABETES

BY

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DISSERTATION

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Abstract

Type 2 diabetes (T2D) has become a major public health priority, especially in older adulthood when disease prevalence rises to ~20%. T2D is related to a host of symptoms and comorbidities including impairments in cognitive function. Despite evidence of the benefits of physical activity to control disease, alleviate symptoms, and improve quality of life, most individuals with T2D do not meet physical activity recommendations. Physical activity is a complex behavior requiring substantial motivational and cognitive resources, as well as continued perseverance. The purpose of this study was to examine mechanisms of physical activity behavior in older adults with T2D in light of both social cognitive theory and neurocognitive perspectives. A secondary purpose of this pilot study was to test if an 8-week physical activity intervention targeting self-efficacy and self-regulatory strategy use would increase physical activity levels six months later.

Older adults with T2D (M_{age} = 61.8 ± 6.4) completed either an 8-week exercise intervention (n = 58) or an online metabolic health education course (n = 58). Measures of physical activity, self-efficacy, self-regulatory strategy use, cognitive function, and disease severity were collected at baseline, post-intervention (month two), and follow-up (month six).

Overall, the results of this study provide some support for the hypothesized self-regulatory, self-efficacy model for physical activity behavior, highlighting specific executive functions including memory and cognitive flexibility. The intervention was effective in increasing physical activity in older adults with T2D. These results contribute to knowledge of physical activity adherence in older adults with metabolic disease.

Keywords: diabetes, physical activity, older adults, self-regulation, self-efficacy

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CHAPTER I: INTRODUCTION

Background

Delaying or preventing the onset of metabolic dysfunction and disease, such as type 2 diabetes mellitus (T2D), is an important public health goal. In 2007, 7.8% of the US adult population had T2D (CDC, 2008), 17.9 million Americans had been diagnosed with diabetes and an estimated 5.7 million have undiagnosed diabetes (CDC, 2008). Approximately 1 in 5 older adults experiences metabolic disease. As the population is increasingly represented by older adult individuals, the long-term consequences of metabolic disease and associated comorbidities are important public health issues with substantial individual, community, and societal impact. T2D is associated with multiple comorbidities including cardiovascular disease, obesity, kidney disease, amputation, blindness and even premature death (CDC, 2008). More recently, there has been evidence indicating that metabolic dysregulation influences brain function (Hendrickx, McEwen, & van der Ouderaa, 2005; Messier, 2005; Ryan, 2005). T2D is associated with impaired cognitive processes (Messier, 2005; Ryan, 2005) and there is some evidence that impaired glucose tolerance and insulin resistance are the driving factors associated with cognitive deficits (Hendrickx et al., 2005). The literature indicates that lifestyle modification, specifically physical activity, can improve the trajectory of disease course (Aizawa et al., 2008; CDC, 2008; Jeon et al., 2007).

Despite evidence of the benefits of physical activity, epidemiological data indicate that most individuals with T2D do not meet physical activity recommendations. A 2003 estimate reported that 23% to 37% of adults with T2D met the recommended levels of physical activity, a percentage that is lower than the national average (Nwasuruba et al., 2007).

Mechanisms underlying physical activity adherence in individuals with T2D are not fully understood and further research is warranted to better understand factors affecting adherence. The REWinD (Regulating Efficacy and Wellness in Diabetes) pilot trial implemented an exercise behavior change intervention for individuals with T2D to further examine specific physical activity determinants. Understanding determinants and moderators of physical activity adherence in populations affected by T2D is crucial for improving disease course.

Social Cognitive Theory (SCT; Bandura, 1986, 2004) specifies a core set of psychosocial determinants (i.e., self-efficacy, outcome expectations, self-regulation and goals, and sociocultural factors (facilitators and impediments)) for effectively understanding a broad range of health behaviors, including physical activity. SCT suggests that behavior change occurs through changes in motivation and self-regulation and hypothesizes that self-efficacy, the central construct, has both direct and indirect influences on behavioral outcomes (Bandura, 2004). Cognitive and motivational elements of self-regulatory behavior may have direct and indirect effects on physical activity behavior.

Adherence to complex behaviors, such as regular physical activity, is difficult. Being physically active requires a combination of difficult tasks such as substantial expenditure of effort, and continued perseverance (McAuley & Blissmer, 2000). Adopting and maintaining physical activity requires one to self-regulate behavior by inhibiting habitual responses (such as playing video games or watching television) and replacing them with other behaviors (such as going for a walk). Two approaches to examining self-regulatory processes involved in behavior change include: 1) the psychosocial paradigm which generally assesses self-reported intentions and goal-setting techniques and 2) the neurocognitive perspective which emphasizes cognitive abilities (McAuley, Mullen et al., 2011). Executive control skills such as planning and

scheduling, inhibition, memory, attention, and task switching are necessary for behavior change. Cognitive function, more precisely executive function, may have the potential to affect an individual's capability to successfully initiate, and maintain, physical activity behavior change. Cognitive control is especially important during the initial phase of behavior change when a new behavior, such as physical activity, is adopted.

Older adults with T2D may represent a vulnerable population who are at heightened risk of non-adherence to physical activity. The development of glucose intolerance coincides with increasing cognitive impairments, which are exacerbated over time and with age. Learning and recall impairments have been observed in middle- and older-adult individuals with metabolic dysregulation. Other observed cognitive impairments include: lower overall intellectual functioning and impaired executive functioning (Hassenstab, Sweat, Bruehl, & Convit, 2010). Impairments in certain executive functioning processes may affect behavior change strategies and behavioral adherence.

The purpose of REWinD was to examine relationships among self-efficacy, self-regulation, cognitive function and physical activity behavior in adults with type 2 diabetes (T2D). The efficacy of an 8-week physical activity intervention targeting self-efficacy and self-regulatory skill use in individuals with T2D was tested compared to an educational control group in increasing physical activity levels.

Objectives & Hypotheses

Objective 1: To examine relationships between physical activity, self-efficacy, self-regulatory strategy use, and cognitive functioning over time. The proposed model is shown in Figure 1. As adherence to physical activity programs is consistently associated with higher levels of exercise-related self-efficacy (McAuley & Blissmer, 2000), the effects of self-regulatory

strategies, including executive functioning, on adherence should partially operate through self-efficacy (McAuley, Mullen et al., 2011). It was hypothesized that baseline use of self-regulatory processes of self-monitoring/goal-setting and cognitive functioning, would indirectly influence physical activity behavior through self-efficacy (see Figure 1).

Objective 2: To compare changes in cognitive function, self-regulatory skill use, and self-efficacy in the intervention and usual care groups. To examine trajectories of metabolic parameters, self-regulatory processes (executive function and self-regulatory strategy use), self-efficacy, and physical activity over the six month time period. It was hypothesized that improvements in self-regulatory processes and self-efficacy would be observed in the intervention group. Additionally, it was hypothesized that metabolic parameters would improve from baseline to month six in the intervention group.

Objective 3: To assess the efficacy of the proposed intervention in increasing physical activity in the target population. It was hypothesized that the intervention group would adopt and sustain increased levels of physical activity across the study period compared to the education condition.

CHAPTER II: LITERATURE REVIEW

This chapter reviews details of T2D, its etiology and primary treatments; the role of physical activity in treatment and prevention of T2D; and associations among T2D, physical activity, and cognitive function. An integrated view of both the psychosocial and neuroscience aspects of self-regulatory processes is proposed. Finally, this review leads to a summary of the present study.

Type 2 Diabetes

The number of individuals affected by metabolic disease, specifically type 2 diabetes (T2D), is considerable. In 2007, 7.8% of the US adult population had T2D (CDC, 2008), which was a 1.5% increase since 2003 (CDC, 2003). It is projected that one in three children now born will go on to develop T2D during her/his lifetime (Englelgau et al., 2004) and each year approximately 1.5 million persons in the US are newly diagnosed with diabetes (CDC, 2008). The prevalence of diabetes increases to 23.1% in persons above 60 years (CDC, 2008), as aging is associated with incremental and gradual losses of glycemic control. However, in recent years, increasingly more people have developed metabolic disease at a younger age (Hendrickx et al., 2005).

Diabetes is a lifelong disease involving chronically high levels of blood sugar. Diabetes can be caused by too little insulin, the molecule which enables glucose to be metabolized by cells, by insulin resistance, or both. Type 1 diabetes, previously known as insulin dependent diabetes mellitus, is characterized by a failure of the pancreas to produce insulin thus resulting in high blood glucose. Type 2 diabetes (T2D), or non-insulin dependent diabetes mellitus, differs in that cells become resistant to insulin, leading to the failure of cells to uptake glucose. The result

is high blood glucose. T2D, according to the American Diabetes Association, is defined as the presence of any of the following four criteria: 1) glycosylated hemoglobin (A1c) value of 6.5% or higher, 2) fasting plasma glucose above 126 mg/dL, 3) 2-hour plasma glucose above 200 mg/dL during an oral glucose tolerance testing using 75g load of glucose and/or 4) classic symptoms of hyperglycemia (including polyuria, polydipsia, and unexplained weight loss) or hyperglycemic crisis. T2D accounts for 90-95% of diabetes cases (American College of Sports Medicine and American Diabetes Association Joint Statement, 2010). T2D is associated with hyperinsulinemia which can lead to pancreatic fatigue and a subsequent insulin shortage.

T2D typically progresses from prediabetes and can continue to worsen with potential outcomes including nerve damage, kidney failure, blindness, heart disease, skin necrosis, amputations, stroke and even death. Prediabetes is a condition that entails impaired glucose control and often leads to a diagnosis of T2D. Following the natural progression of the disease, the majority of individuals diagnosed with prediabetes are eventually diagnosed with diabetes (Edelstein et al., 1997). Approximately 57 million Americans have prediabetes and therefore are at risk for development of further metabolic disease and other complications (Pour & Dagogo-Jack, 2011). Research has shown that T2D is associated with much comorbidity including cardiovascular disease, obesity, kidney disease, amputation, blindness and possibly premature death (CDC, 2008).

Genetic and environmental factors are strongly implicated in the development of T2D. Exact genetic indicators are complex and not well understood. However, it has been well-established that age, obesity, and physical inactivity are associated with increased risk (American College of Sports Medicine and American Diabetes Association Joint Statement, 2010). Risk factors for metabolic disease are well-documented and intervention techniques, including

lifestyle modification and pharmacologic treatment, have been shown to prevent, delay or even in some cases reverse disease course (Pour & Dagogo-Jack, 2011).

Diabetes & Cognitive Function

Recent evidence suggests that disruptions in glucose regulation are associated with cognitive impairment (Hendrickx et al., 2005). T2D and the associated inability to control blood glucose are related to impaired cognitive processes (Messier, 2005; Ryan, 2005) and there is some evidence that impaired glucose tolerance, or pre-diabetes, may be associated with cognitive deficits (Hendrickx et al., 2005).

Both metabolic dysregulation and cognitive decline have features in common with aging. Both cognitive impairments and brain structural aberrations have been reported in metabolic disease (Gold et al., 2007; Convit et al., 1997; Leibson et al., 1997). Such cognitive impairments are most often observed in older adults with metabolic disease. However, early onset of T2D, poor glycemic control, and vascular disease appear to result in cognitive decline at an earlier age (Awad, Gagnon, & Messier, 2004). Metabolic disease is associated with health risk factors such as obesity, hypertension, dyslipidemia, disturbed cortisol control, and chronic low-grade inflammation. All of these factors influence cognitive function independently and may collectively contribute to the metabolic-cognitive syndrome. Cognitive deficits are also correlated with glucose intolerance, insulin resistance or untreated diabetes and attenuation of cognitive impairments have been observed by treatments that improve glycemic control (Awad et al., 2004).

Not all cognitive functions are affected equally by metabolic disease. Declines in information processing speed and declarative memory have been consistently associated with metabolic disease (Awad et al., 2004; Ryan, 2005). Tasks dependent on the hippocampus and

surrounding structures seem to be especially vulnerable (Convit, 2005). It is important to note that aging is correlated with hippocampal deterioration. Gold and colleagues (2007) examined hippocampal performance in age, sex, and education matched healthy and diabetic middle-aged individuals. Both hippocampal structure and function were impaired in the individuals with T2D. Those with T2D showed decreased performance on hippocampal-dependent tasks, such as Weschler memory scale and the California verbal learning test short and long, but there was preservation of other cognitive functions such as attention and inhibition. Atrophy of the hippocampus was associated with diabetes related variables, especially glycosylated hemoglobin (HbA1c). Gold and colleagues concluded that middle-aged individuals with well-controlled diabetes still experience clear deficits in hippocampal based memory and structure atrophy.

Additionally, hippocampal volume reductions and white and gray matter abnormalities have been linked to poor glycemic control associated with metabolic disease (den Heijer et al., 2003; Gold et al., 2007; Jongen et al., 2007; Korf, Scheltens, White, & Launer, 2006; Kumar et al., 2008; van Harten, Oosterman, Potter van Loon, Scheltens, & Weistein, 2006). Associations between metabolic disease and associated cardiovascular risk factors together are related to decrements in prefrontal regions (Kumar et al., 2008).

In a review, Awad and colleagues (2004) concluded that decrements in processing speed and immediate verbal memory in T2D have been consistently observed. A smaller proportion of studies showed significant performance differences in nonverbal memory, arithmetic, phonemic and categorical fluency. Cognitive impairments observed in nonverbal memory and executive function with T2D were inconsistent. Such variability could be due to methodological differences, task/test sensitivity or sample size and insufficient statistical power. A key variable in the metabolic cognitive impairment phenomenon is glucoregulatory control. Individuals with

poor glucoregulatory control, which includes untreated T2D and non-diabetic conditions with impaired glucose tolerance, are more likely to show cognitive impairment compared to controls than individuals with well-controlled T2D. The largest effect sizes were observed in studies in which the participant mean age was above 65 and in which higher HbA1c levels were observed (Awad et al., 2004). The literature suggests that insulin resistance is primarily important in metabolic related cognitive impairments. Metabolic-cognitive impairments may start as early as the fifth decade of life and worsen with age.

Several mechanistic propositions related to the metabolic cognitive syndrome have been offered throughout the literature including obesity, stress and cortisol, chronic low-grade inflammation, and cerebral nutrient availability. Each of these pathways has some empirical support, however, there are still many questions concerning the precision and public health applicability of each mechanism. Following is a brief description of each proposed mechanism.

Obesity

Obesity is often associated with metabolic syndrome, insulin resistance, and T2D. There is an expanding literature linking obesity to compromised cognitive functioning independent of glucose control. Gunstad and colleagues (2007) observed a relationship between executive dysfunction and BMI greater than 25kg/m^2 in a sample of male and female adults. Specifically, global gray matter atrophy (Taki et al., 2008) and frontal and medial-temporal lobe abnormalities (Gustafson, Lissner, Bengtsson, Bjorkelund, & Skoog, 2004; Pannacciulli et al. 2006) are related to obesity. Gustafson and colleagues (2004) found in a sample of older adult women that individuals with cerebral temporal lobe atrophy had 1.1-1.5kg/m^2 higher BMI than those without cerebral atrophy. The risk of cerebral atrophy increased 13-16% with every additional BMI unit.

Visceral obesity, reflected by waist-to-hip circumferences has been associated with reductions in hippocampal volume and white matter pathology (Jagust, Harvey, Mungas, & Haan, 2005). Prospective studies have observed associations between accumulation of visceral adipose tissue and cognitive decline in older adults (Gustafson, 2006; Whitmer et al., 2008). Additionally, central adiposity has been associated with reductions in hippocampal volume and increased white matter pathology where a one standard deviation increase in waist to hip ratio was associated with a .2 standard deviation decrease in hippocampal volume and a 27% increase in white matter hyperintensities (Jagust et al., 2005). Additionally, body mass index is associated with lower gray matter volume (r = -.19, p < .0001) (Taki et al., 2008). Obesity is associated with brain structure and impaired function. The physiological mechanisms and pathways of this effect remain unclear, probably because multiple, complex mechanisms are responsible for the obesity-related cognitive impairments. However, proposed behavioral mechanisms suggest that individuals with impaired cognition function may have more difficulty with weight control behaviors such as planning, reasoning and problem solving.

Stress and Cortisol

Cortisol dysregulation is associated with both T2D and impaired cognitive function (Bruehl et al., 2007). Bruehl and colleagues (2009) examined the metabolic cognitive syndrome with a specific aim of identifying modifying factors of cognitive performances. A comparison of T2D adults and age-matched controls without T2D indicated that T2D negatively impacted hippocampal volume and performance on specific verbal memory tasks. The participants with T2D had reduced suppression of cortisol release after dexamethasone (synthetic glucocorticoid) injection compared to the participants without T2D. However, cortisol release in response to cortisol releasing hormone did not differ between groups, suggesting that the feedback

mechanism regulating cortisol levels was impaired higher up in the hypothalamus-pituitary-adrenal (HPA) axis in participants with T2D. It does appear that diabetes impacts the HPA axis. Individuals with poorly controlled diabetes show hyperactivity of the HPA axis which results in higher levels of circulating cortisol. Chronic cortisol elevations, which are often observed in metabolic disease, contribute to memory and learning impairments by altering synaptic plasticity and reducing neurogenesis (Stranahan et al., 2008).

Inflammatory factors

Inflammatory markers, such as C-reactive protein (CRP) and fibrinogen, appear to contribute to the metabolic-cognitive syndrome (Skalicky et al., 2008; Fernandez-Real & Pickup, 2008; Sweat et al., 2008). Pro-inflammatory cytokines such as IL-6, which are elevated in obesity and T2D, have been linked to cognitive decline (Weaver et al., 2002). Additionally, chronic low grade elevations in CRP have been seen to be independently predictive of cardiovascular disease and influence the development of metabolic disease, including T2D (Skalicky et al., 2008).

Cerebral Nutrient Availability

Another proposed mechanism for the metabolic cognitive syndrome is the reduced availability of nutrients and glucose to cerebral tissues. Reduced cerebral blood flow has been observed in patients with T2D and increasing BMI (Selim, Jones, Novak, Zhao, & Novak, 2008). The hypothesis that diminished glucoregulatory control is associated with impaired cognitive and neuropsychological performance has been well-established (Awad et al., 2004). Interestingly, cognitive deficits in young adults with type 1 diabetes appear to be related to the number of hypoglycemic events experienced (Hershey, Craft, Bhargava, & White, 1997) and this observation extends strongly to T2D. Several studies have illustrated cognitive measurement

during a fasted state in individuals with glucose intolerance revealed significant decrements compared to age matched controls. However, the performance deficits were reduced after ingesting 50g of glucose (a fed state) (Kaplan, Greenwood, Winocur, & Wolever, 2000; Kaplan, Greenwood, Winocur, & Wolever, 2001). These effects were not due to fasting, as the patterns were not consistent with hypoglycemia and the effect of the ingested glucose load was dose-dependent.

These mechanisms help to clarify why metabolic disease negatively affects cognitive performance. A logical next line of inquiry is how these impairments affect the very behaviors, including physical activity, which can ameliorate both metabolic disease and cognitive decline. It has been established that physical activity is an effective way to control and ameliorate metabolic disease progression, yet it remains difficult for many individuals with T2D to be physically active. Whether executive function plays a role in physical activity adherence in T2D remains to be determined.

Diabetes & Physical Activity

The current body of knowledge emphasizes the importance of successful lifestyle modifications to reverse or prevent both cognitive and metabolic disease progression. Lifestyle intervention is crucial for prevention of T2D and delaying the progression and concomitant health consequences of T2D. Indeed first-line therapy for T2D is lifestyle modification (Grundy et al., 2005) as two main contributors to the development of these diseases are physical inactivity and poor diet (Aizawa et al. 2008; CDC, 2008). Lifestyle modification interventions can substantially improve trajectory of the disease course (Aizawa et al., 2008; CDC, 2008). However, adherence remains an issue.

Specifically, physical activity has been consistently associated with reductions of risk in developing diabetes and continued progression of metabolic disease (Jeon et al., 2007), as physical activity alone, with or without weight loss (Duncan et al., 2003), improves glucose tolerance and insulin sensitivity. Both in human and animal models, aerobic exercise results in marked improvements in whole body insulin sensitivity (Arciero, Vukovich, Holloszy, Racette, & Kohrt, 1999; Duncan et al., 2003; Luciano et al., 2002; Matos et al., 2010). Touati et al. (2011) reported that exercise reversed metabolic syndrome in high-fat diet-induced obese rats. Both exercise training and diet changes reduced adiposity, improved glucose and insulin levels and the lipid profile, and decreased hypertension. However, exercise was more effective, compared to caloric restriction, at improving plasma levels of biomarkers related to acetylcholine and insulin. Their findings illustrate that both exercise and diet can improve symptomology associated with metabolic syndrome and exercise produces these benefits with or without dietary modification. Additionally, Matos et al. (2010) showed that acute exercise ameliorates whole body insulin sensitivity in diabetic mice. Mice swam for two 3-hour periods with a 45 minute rest in between, which was followed, eight hours later, by an insulin tolerance test. Results showed an increase in the insulin-signaling pathway in skeletal muscle, increased GLUT4 membrane expression, and improved glucose disappearance rate in the diabetic mice who had exercised. These findings hold true in human research. The American College of Sports Medicine and the American Diabetes Association (2010) issued a joint statement on *Exercise and Type 2 Diabetes*, noting that physical activity and exercise causes increased glucose uptake into active muscles cells. Insulin-stimulated glucose uptake into skeletal muscle is the predominant mechanism at rest, which is impaired in T2D. However, during activity, muscle-contraction mediated glucose uptake via a separate, additive mechanism occurs (American College of Sports Medicine and

American Diabetes Association Joint Statement, 2010). Muscle-contraction mediated glucose uptake remains functional in T2D. Acute moderate-intensity aerobic exercise improves blood glucose and insulin action with a minimal risk of exercise-induced hypoglycemia. Moreover, acute physical activity can result in improvements in systemic insulin action lasting from 2 to 72 hours.

Chronic exercise training shows even more powerful results, because chronic physical activity improves insulin action, blood glucose control, and fat oxidation and storage. Chronic aerobic exercise training also may result in slight reductions in LDL cholesterol and systolic blood pressure. The disruption in lipid metabolism balance appears to be crucial in the development of insulin resistance (Cusi, 2009). Interventions, such as aerobic endurance exercise, which improve lipid homeostasis, appear to potentially reverse lipid-induced insulin resistance. Indeed, increasing lipid oxidation helps improve insulin sensitivity in skeletal muscle in high-fat fed rodents (Yaspelkis, et al., 2007) and obese humans (Goodpaster, Katsiaras, & Kelley, 2003). Finally, chronic exercise training is linked to increased weight loss and better weight management, which is independently associated with improvement in T2D status and symptomology (American College of Sports Medicine & American Diabetes Association Joint Statement, 2010). Exercise and weight loss combined appear to have the most substantial impact on insulin resistance (Cusi, 2009). However, it can be discouraging for individuals to exercise when weight loss is minimal to none. Duncan and colleagues (2003) concluded that even though weight loss is largely related to significant metabolic risk management, physical activity can improve glucose tolerance and insulin sensitivity in the absence of weight loss.

Cardiorespiratory fitness and physical activity are clearly linked to lower risk of developing insulin resistance, obesity, cardiovascular disease, metabolic syndrome, and T2D

(LaMonte, Blair, & Church, 2005; Sui et al., 2007). Increased muscle mass and decreased fat tissue, as a result of physical activity, contribute to better glucose absorption (Awad et al., 2004). Increased muscle mass increases the number of muscle cells capable of contraction-mediated (and insulin-mediated) glucose uptake. Additionally, during exercise itself, skeletal muscle cells consume massive amounts of glucose. Moderate intensity exercise training combined with weight loss induces mitochondrial biogenesis, improved mitochondrial function, and increased size, which enables more ATP production. Moreover, there are multiple insulin signaling pathways at several levels, which improve with exercise training (Cusi, 2009). This, combined with other mechanisms of exercise to improve T2D disease status, makes a strong argument that physical activity is an essential and effective treatment for T2D.

Many studies have examined aerobic exercise effects on glucose metabolism but recent research suggests that combined aerobic and anaerobic exercise is optimal for individuals with T2D (Church et al., 2010). Church and colleagues (2010) observed greater reductions in HbA1c levels with combined chronic aerobic and resistance training than with either aerobic or resistance training alone. Currently the American Diabetes Association (ADA) is recommending both regular aerobic and anaerobic exercise. The recommendations for aerobic training are: at least 3 days/week with no more than two consecutive days between bouts, at a moderate intensity of about 40-60% of maximal aerobic capacity, with duration summing to at least 150 minutes/week. Resistance training should be done at least twice weekly on nonconsecutive days, at a moderate or vigorous intensity (50% of 1-RM or 75-80% of 1-RM), with at least 5-10 exercises involving major muscle groups, and with 8-10 repetitions where at least one set of repetitions nears failure (American College of Sports Medicine & American Diabetes Association Joint Statement, 2010).

Despite evidence of the benefits of physical activity for health and ADA's position that it is a cornerstone of treatment, epidemiological evidence suggests that most individuals with or at risk for T2D do not meet physical activity recommendations (Morrato, Hill, Wyatt, Ghushchyan, & Sullivan, 2007). A 2003 estimate reported that between 23% and 37% of adults with T2D were meeting the recommended levels of physical activity (Nwasuruba et al., 2007). Taylor et al. (2010) reported that 38% of individuals with prediabetes were meeting the recommended amount of physical activity. As of 2007, 48.8% of Americans were meeting the physical activity recommendations (CDC, 2007). Individuals affected by T2D are less physically active than their peers even though physical inactivity is a risk factor for further disease progression.

Much research has been dedicated to developing techniques and interventions to help those with T2D be physically active and include the Diabetes Prevention Program (DPP), the Look AHEAD (Action for Health in Diabetes) Study, and the Healthy-Living Partnerships to Prevent Diabetes (HELP PD) Project. The DPP was a major multicenter clinical research trial examining whether weight loss with dietary changes and increased physical activity or treatment with oral diabetes drug metformin could prevent or delay the onset of T2D in study participants. The lifestyle group was trained in diet, physical activity, and behavior modification. The medication group took 850mg twice a day of metformin—a commonly prescribed diabetes medication. There was a third control placebo group. All participants were overweight with prediabetes. The DPP ended a year early due to the remarkable data. Those in the lifestyle group decreased their risk of developing T2D by 58%. Lifestyle changes worked particularly well for participants aged 60 and older, reducing their risk by 71 percent. The medication group saw lower, yet significant, risk reduction of 31%. Additionally, metformin was least effective in individuals aged 45 and older (http://diabetes.niddk.nih.gov/dm/pubs/preventionprogram/). The

impact of the DPP continues to grow as researchers and communities are building upon and delivering the intervention.

The Look AHEAD trial was a multicenter randomized clinical trial comparing effects of an intensive lifestyle intervention versus diabetes support and education (control) on incidence of major CVD events in overweight and obese persons with T2D. Four-year results indicated that the lifestyle group lost ~6% more weight and improved cardiorespiratory fitness by about 11% more compared to the education group. HbA1c, diastolic blood pressure, levels of HDL cholesterol, and triglycerides also significantly improved in the lifestyle group. Conclusions suggest that an intensive lifestyle intervention can produce sustained metabolic improvements in overweight/obese individuals with T2D (Look AHEAD research group, 2010).

The HELP PD project was a community based translation of the DPP. The DPP program was delivered through a diabetes education program and was delivered by community health workers, who were volunteers with well-controlled T2D. The primary outcome was mean fasting glucose over 12 months of follow-up, adjusting for baseline glucose. As was found in the DPP, the lifestyle intervention participant experienced significantly greater decreases in blood glucose, insulin, weight, and waist circumference compared to a control. The HELP PD program was a successful translation of the DPP into a community (Katula et al., 2011).

These studies underscore the importance of lifestyle change and physical activity in preventing and managing T2D, especially when combined with aging. However, these studies were all structured, strict on-site programs, which devoted specific resources to ensuring program adherence. Effectiveness research is now warranted as the delivery of the DPP to every individual with T2D promises to be a costly endeavor. Examining determinants of behavioral

control in individuals with T2D may help the transition of the state of research from efficacy trials to translational lifestyle interventions.

Physical Activity and Cognitive Function

Prevention, delay or even reversal of symptoms related to T2D, can be achieved through lifestyle modification. Treatments that improve glycemic control attenuate cognitive impairments associated with metabolic disease (Awad et al., 2004). Physical activity and fitness are related to improved brain structure and function such as better cognitive performance and improvements in brain tissue integrity and volume.

Much research has focused on physical activity, fitness and cognitive performance. Spirduso and Clifford (1978) examined differences between young and old athletes and sedentary individuals on simple choice, movement time tasks. The active/fit older adults performed significantly better than the sedentary older adults; in fact they were comparable to the sedentary young adults. Cognitive benefits from fitness were smaller in the young adults compared to the older adults. These results have been corroborated by other studies (Dustman, Emmerson, & Shearer, 1994; Etnier et al., 1997).

A meta-analysis conducted by Colcombe & Kramer (2003) examined fitness effects on cognitive function in older adults (55-80 years old). They examined longitudinal intervention (18 studies from 1996 to 2001) effects of exercise on cognitive processes, including executive control tasks. Results indicated that control and intervention groups, collapsed from 18 studies, both improved over time on cognitive tasks. However, the improvement in the intervention exercise group was significantly greater compared to control. Executive processes displayed the greatest exercise-related effects, which were significantly greater than the effects on any other type of cognition. Exercisers also improved more than control subjects on controlled, spatial, and

speed tasks. Colcombe & Kramer concluded that fitness has strong, yet selective, beneficial effects for cognition.

Chodzko-Zajko & Moore (1994) suggest that tasks requiring specific, effortful processing (tasks associated with the hippocampus and the frontal cortex) display greater fitness associated improvements compared to tasks consisting of automatic processing (tasks related to mid-brain or brainstem locations). Schneider and Shiffrin (1977) laid the foundation for this *controlled-processing hypothesis* by proposing a theory of skill acquisition in which as skills become more practiced they switch to automatic processing. Kramer and colleagues (1999) demonstrate that improvements in fitness are related to enhancements in executive control processes such as coordination, inhibition, scheduling, planning, and working memory. These executive control tasks do not become automatic with practice yet consistently require mediation by a "central executor" (Colcombe & Kramer, 2003). Unfortunately, the brain areas that support executive control processes have been illustrated to be disproportionately sensitive to aging (Colcombe & Kramer, 2003) and metabolic disease (Awad et al., 2004; Bruehl et al., 2009; Gold et al., 2007; Ryan, 2005).

In addition to effects of fitness, exercise itself, acute and chronic, appears to have beneficial effects on cognition (Angevaren, Aufdemkampe, Verhaar, Aleman & Vanhees, 2008; Etnier, Nowell, Landers, & Sibley 2006; Hillman, Erickson, & Kramer, 2008; Kramer & Erickson, 2007; Sibley & Etnier, 2003). Smith and colleagues' (2010) meta-analytic review of aerobic exercise and neurocognitive performance analyzed twenty-nine randomized controlled exercise trials finding that individuals who received aerobic exercise training demonstrated modest improvements in attention and processing speed, executive function, and memory. The

effect size was much smaller compared to Colcombe and Kramer's review largely due to the fact that the review inclusion criteria allowed for much younger samples.

Chronic moderate-intensity aerobic exercise results in increased gray matter volume in the prefrontal cortex after 6 months of exercise (Colcombe et al., 2006) and increased hippocampal volume after one year of exercise (Erickson et al., 2011), compared to a non-aerobic exercise attention control group. Weinstein and colleagues (2011) reported that prefrontal cortex volume mediated the relationship between cardiorespiratory fitness and executive functioning.

Several mechanisms of the effect of physical activity on cognitive function have been explored yet the picture as a whole remains somewhat unclear. Exercise does appear to elicit a neuroprotective effect (Kinni et al., 2011). The precise mechanism of exercise-related neuroprotection remains unclear. However, one proposed mechanism involves the concept of exercise-training-associated increases in the body's capacity to spare fuel, such as glucose, for cerebral use and to increase the efficiency of metabolism. Seifert and colleagues (2009) examined the cerebral metabolic response in exercise training and observed that post-training cerebral metabolism appeared to be attenuated in response to a submaximal test. More specifically, individuals post-training exhibited lower carbohydrate uptake and maintained cerebral oxygenation in response to submaximal exercise. Kinni and colleagues examined several proteins key to cerebral glucose uptake and metabolism, such as GLUT3 and PFK, in rats post exercise. GLUT3 protein translation and protein levels and those of PFK were increased after both of the exercise conditions compared to the control.

Environmental factors are an important consideration in explaining the plethora of symptoms associated with the metabolic-cognitive syndrome. Important environmental factors,

such as physical inactivity, overfeeding, psychological stress, sleep deprivation, and high fat intake influence disease course and progression. These environmental mediators likely interact with genetic vulnerabilities (many of which remained undiscovered) (Hendrickx et al., 2005).

The current literature on metabolic-cognitive syndrome suggests that lifestyle interventions emphasizing physical activity could have the potential to prevent, delay or ameliorate cognitive decrements. However, systematic examination of physical activity on metabolic-cognitive syndrome has yet to be conducted.

Social Cognitive Theory & Physical Activity Behavior

In light of the beneficial effects of physical activity in this population, regular physical activity is highly recommended. However, behavioral adherence is complex. Adoption of physical activity is a difficult task for many and attrition estimates are as high as 50% within the first six months (Dishman, 1982). Social Cognitive Theory (SCT; Bandura, 1986, 1997, 2004, 2005) has been shown to be useful in explaining and predicting physical activity behavior. SCT's constructs together predict behavior. Self-efficacy, the belief in one's own capabilities to successfully carry out a course of action, is the core construct of SCT. Self-efficacy is an important determinant of effort expenditure, activity choice, and the degree of persistence an individual puts forth in the face of barriers or failure —all of which are integral in the sustained adoption of physical activity (McAuley & Blissmer, 2000).

SCT (Bandura, 1986; 1997; 2004) specifies a core set of psychosocial determinants (i.e., self-efficacy, outcome expectations, self-regulation and goals, and sociocultural factors) for effectively understanding a broad range of health behaviors, including physical activity. SCT suggests that behavior change occurs through changes in motivation and self-regulation and

hypothesizes that self-efficacy, the central construct, has both direct and indirect influences on behavioral outcomes (Bandura, 2004). Specifically, within the SCT framework, behavior is viewed within a triadic, reciprocal paradigm where behavior, individual factors, and environment influence each other (see Figure 2).

Most human behavior is determined by an interaction of factors, so individuals are contributors to, rather than the sole determiner of, events. These phenomena are grounded in the important concept of human agency. Agency refers to behavior done intentionally. Beliefs of personal efficacy and ability are key factors of human agency (Bandura, 1986). If people think they are incapable of producing certain results, it is more likely that they will not attempt to achieve those results. When beliefs in personal abilities are strong, self-influence brings about the desired results, assuming one has the motivation and the skills to carry out the behavior. This agency related causation relies on efficacy and cognitive self-regulation (Bandura, 1997). Thus cognitive and motivational elements of behavior may have direct and indirect effects on physical activity behavior.

Each of the constructs within SCT, outcome expectations, sociostructural factors, goals/self-regulation, and self-efficacy, plays an important role in understanding, explaining, and predicting human behavior. Outcome expectations involve the cognitive anticipation of results from certain behaviors. In terms of physical activity, outcome expectations reflect beliefs that physical activity will bring about certain results (i.e. improved strength, weight loss, lower cardiovascular risk, sore muscles). Generally, people who believe that desired outcomes are determined by their behavior, such as physical activity, are much more likely to be engaged than those who have fatalistic perspectives. Thus, the controllability of outcomes is somewhat linked

to personal efficacy. Without self-efficacy, outcome expectations alone fail to consistently motivate behavior.

Self-regulatory aspects of the SCT model involve behaviors such as goal-setting, self-evaluation, self-rewarding, and self-monitoring. Self-regulatory strategies mediate the relationship between self-efficacy and physical activity (Dishman et al., 2005). Bandura (2005) states that health promotion should start with goals. Self-regulation is a construct within SCT that incorporates goal-setting, planning, self-monitoring, self-regulating, and self-rewarding. "Self-management is good medicine" (Bandura, 2005, p. 245). However, health habits are not changed through willpower alone, but through self-management requiring motivational and self-regulatory ability and skills. Self-management can be summarized with three general categories: 1) self-monitoring of behavior and the cognitive condition under which one is engaged, 2) adoption of goals to guide efforts and strategies, and 3) self-reactive factors which include self-motivating incentives and social support to sustain desired behavior (Bandura, 2005). Maes & Karoly (2005) conceptualize self-regulation as a triadic process by which individuals influence their own health habits. In their goal-guidance model, goal adoption enables self-directed change; implementation strategies help turn goals into productive action; and maintenance strategies help to sustain behavioral changes. Inherent in self-regulation theory is the assumption that cognitive factors are significant contributors to health behavior (Bandura, 2005).

Most dominant models of individual self-regulation and health behavior neglect biological components and focus entirely on psychosocial variables. Neuroscience research suggests that there is a role for brain function in explaining behaviors that require active self-regulation (Hall, Elias, & Crossley, 2006). There are several neuroscientific theories regarding self-regulation. One of the more commonly cited theories is the self-regulatory depletion model,

which posits that self-regulation is a limited resource and engagement in one domain of self-regulation can indeed result in inability to self-regulate in another domain (a.k.a. self-regulatory depletion). A classic example is one that Wagner & Heatherton (2010) describe where expending energy on a difficult attention control task lead to subsequent poor emotional regulation. Individuals experienced one of two conditions on a cognitive task: 1) congruent Flanker and 2) incongruent Flanker. Then they were required to perform a task that required emotional regulation, such as interpersonal confrontation or denying a fresh tray of baked cookies. Those who completed the incongruent Flanker first did significantly worse on the subsequent emotional regulation task compared to those who did the congruent condition first.

In other research, Wagner & Heatherton focus on the epitome of self-regulatory resource depletion: dieting. Functional MRI imaging was collected after varying individuals underwent three differing conditions while in the waiting area before the MRI: 1) dieters in the presence of a candy bowl, 2) dieters without the presence of a candy bowl, and 3) non-dieters in the presence of a candy bowl. The dieters in the presence of the candy bowl showed increased food cue activity in the nucleus accumbens. These results suggest that temptations are only resource depleting to the extent that people have the goal of resisting them. Furthermore, it suggests that goal-oriented behavior may be at higher risk of regulatory depletion than other behaviors.

It is logical to next inquire what is the resource that is actually being depleted during self-regulatory failure. Gailliot and colleagues (2007) suggest that the resource necessary in the self-regulatory depletion model is glucose. Gold (1995) established that blood glucose influences cognitive performance, especially memory, in animal models. Self-regulatory tasks require adequate levels of circulating blood glucose. Jondies et al. (1997) found that local brain glucose metabolism increases as a task gets more difficult. Indeed blood glucose dysregulation is

associated with an array of cognitive impairments, both structural and behavioral (Awad et al., 2004; Gold et al., 2007; Convit et al., 1997; Leibson et al., 1997; Hendrickx et al., 2005). Chronic hyperglycemia, indicating glucose remains in the blood unable to enter the cells for prolonged periods of time, contributes to structural pathologies such as white and gray matter atrophy, white matter lesions, increased hyperintensities, and higher ventricular volume as well as impairments in behavioral task performance.

My colleagues and I recently discovered that pre-testing blood glucose levels were associated with decrements in working memory performance in a small sample of middle- and older-adults (n= 60, M_{age}=61±7.9) with and without T2D. The results indicated that individuals with acute hyperglycemia performed worse on the working memory serial n-back task. The serial n-back task has three conditions. In the zero-back condition, participants identified the current shape. Subsequently, they identified whether the current shape was the same or different from the previous shape (one-back) or two shapes ago (two-back). In addition to a between subjects effect of blood glucose on n-back performance, an interaction between task accuracy and blood glucose emerged where individuals with initial hyperglycemia experienced a steeper decline in n-back accuracy. The pre-testing blood glucose level, while accounting for diabetes status, age gender, BMI and comorbidity, affected the slope of decline in working memory accuracy. These data suggest that acute hyperglycemia contributes to cognitive impairments beyond those associated with diabetes status. Glucose dysregulation may influence individual ability to sustain adequate memory function (Manuscript currently in review). Despite evidence that blood glucose impacts cognitive functioning, more research, specifically imaging studies, is required to clarify mechanisms of action.

Continuing to highlight the neuroscientific perspectives of self-regulatory capacity, self-regulation is related to the "top-down" control of the prefrontal cortex on the midbrain and brainstem. Self-regulatory failure can be argued to involve disruption in the top down communication/control (Braver & Barch, 2002; Wagner & Heatherton, 2010). Such a failure could be due to decreases in the integrity of prefrontal cortex tissue or intra-cortex communication. Recent findings indicate that glucose dysregulation is associated with diminished integrity of the brain's default mode network (Musen et al., 2012).

Self-efficacy and self-regulatory strategy use have been consistently associated with physical activity behavior. Executive function and cognitive resource allocation have also been associated with physical activity behavior (McAuley, Mullen et al., 2011). It is important to note that self-regulatory strategies can require complex planning, evaluation, assessment and trouble-shooting techniques. The neurocognitive literature incorporates a biological perspective by examining abilities to successfully perform tasks such as planning, decision-making, error correction, inhibition and troubleshooting (Stuss & Alexander, 2000). Bandura has proposed that SCT integrates this biological/cognitive perspective with motivational elements in self-regulated behavior (Bandura, 1997). Cognitive skills, specifically executive function, are necessary for self-regulation including planning, scheduling, inhibiting old habits, incentivizing, and implementation strategizing.

Hall and colleagues (2008) demonstrated that unique variance in health behavior is predictable by accounting for individual differences in executive function and that executive function moderates the association between intentions and behavior. In a multiple study project, Hall and colleagues examine performance on a computer-based executive function task (Go/NoGo task) which was followed by a 1-week behavioral period of identifying intentions and

goals related to physical activity and dietary behavior. At the end of this week, participants were asked to report physical activity levels. A hierarchical linear regression revealed that both behavioral intention (goals) and the Go/NoGo reaction times predicted unique variance in physical activity after controlling for demographic variables.

Data collected from a randomized controlled exercise trial by McAuley, Mullen and colleagues (2011) integrated the neuroscience and social cognitive perspectives as a way to approach understanding exercise adherence. They hypothesized that self-efficacy mediated the relationship between self-regulatory capacity and sustained exercise behavior. Older adults completed measures of executive function, self-reported self-regulatory strategy use, and self-efficacy before and during a 12 month exercise intervention. Results suggested that some executive function measures and self-regulatory strategy use influences self-efficacy and consequently exercise adherence. Additionally, there were significant indirect effects of self-regulatory strategy use and executive function, on program adherence through self-efficacy. Conclusions indicated that higher levels of executive function and self-regulatory strategy use at the start of an exercise program enhance beliefs in exercise capabilities which can lead to greater exercise adherence. These data have implications for both further development of interventions targeting exercise behavior and public health approach to physical activity. These data suggest that self-regulatory capacity, both social cognitive and neurocognitive, is key to long term physical activity, which influences strategies to improve physical activity adherence, especially in vulnerable populations such as older adults and individuals with cognitive impairments. Interventions that target both social cognitive constructs and neurocognitive abilities to increase self-regulatory capacity may prove to be beneficial for improving physical activity adherence.

Self-regulatory strategies and self-efficacy enhancement are particularly critical when behavior change is first adopted when cognitive processes and affective reactions are integral to success (Bandura, 2004). Overall, individuals who regularly engage in such strategies, such as self-regulation or time management, are likely to have higher perceptions of their own capabilities to engage in physical activity which improves long-term adherence. Additionally, individuals who are able to multi-task, remember accurately, and inhibit habitual behaviors (such as sedentary activities) may be more successful in adopting and maintaining physical activity (McAuley, Mullen et al., 2011).

As the development of glucose intolerance coincides with increasing cognitive impairments, the ability to use self-regulatory strategies may be compromised in populations experiencing T2D. Tasks dependent on the hippocampus and surrounding structures such as memory seem to be especially vulnerable to glycemic dysregulation (Convit, 2005). Also, declines in information processing speed have been associated with diabetes (Ryan, 2005). However, it remains unclear how these deficits may impact everyday functioning. The ability to successfully learn self-regulatory strategies may be compromised which in turn affects self-efficacy, whereas successful learning and reinforcement may serve to enhance self-efficacy. The metabolic-cognitive constellation of symptoms may affect individual abilities to plan, persist, and self-regulate physical activity, which may contribute to the lower than average rates of adherence to physical activity levels in populations with metabolic disease. Teaching individuals at risk to effectively self-regulate physical activity behavior could be a powerful tool to improve exercise adherence and potentially ameliorate the disease course of T2D.

The Present Study

Despite evidence of the benefits of physical activity for metabolic health, epidemiological evidence suggests that both individuals with metabolic disease and those at risk of developing metabolic disease do not meet physical activity recommendations. A 2003 estimate reported that between 23% and 37% of adults with T2D were meeting the recommended levels of physical activity (Nwasuruba, Khan, & Egede, 2007). Taylor et al. (2010) found in an analysis of physical activity and health-related quality of life in individuals with prediabetes that 38% of individuals with prediabetes were meeting the recommended amount of physical activity. As of 2007, 48.8% of Americans were meeting the physical activity recommendations (CDC, 2007). It appears that individuals at risk for developing T2D are less physically active than their average peers.

The deleterious effects of impaired glucose tolerance and early stage T2D on cognitive function appear reversible. However, with aging and progression of the disease, cognitive deficits may be irreversible, especially as comorbidities develop (Awad et al., 2004). Treatments that focus on glucose control may be extremely influential in ameliorating both metabolic and cognitive effects present in the metabolic-cognitive syndrome.

The REWinD Trial examined how self-efficacy, self-regulatory strategy use and executive function influence physical activity behavior over time. The primary outcome was physical activity level at month six. Firstly, it was hypothesized that self-regulatory capacity (self-regulatory strategy use and executive function) would indirectly influence physical activity behavior through self-efficacy.

It was hypothesized that self-efficacy and self-regulatory capacity would increase over the six-month study period and there would be intervention effects. It was hypothesized that improvement in self-efficacy and self-regulatory capacity would be related to physical activity.

Finally, it was hypothesized that the intervention group would adopt and maintain higher levels of physical activity over the course of the intervention and follow-up.

CHAPTER III: RESEARCH DESIGN AND METHODS

Sample and Recruitment

Individuals with T2D or metabolic syndrome within ages 50 to 75 years were recruited primarily from Champaign County (population 186,000) and Vermilion County (population 81,625). Champaign County has an estimated 8.2% prevalence of diagnosed T2D and Vermilion County's estimate is a prevalence rate of 8.6% (CDC, Diabetes Data and Trends). The area has some moderately sized urban/suburban areas (Champaign-Urbana, Decatur, and Danville), some smaller suburban areas and rural residential areas. Recruitment was heaviest in the Champaign-Urbana area. Participants were recruited via print, internet, email, physician/diabetes educator, and direct mailing advertisement. Recruitment partners included diabetes educators, physicians, and the clinical research division at Carle Clinic. Carle additionally sent approximately 2,000 direct mail letters to patients with T2D over the age of 50 years. The study was advertised as an opportunity for older adults with T2D to participate in a free exercise-centered health program and contribute to science. Interested individuals contacted us via phone or email. There was a drawing at the end of the study for four (two per group) $50 gift certificates to Amazon.com for participant appreciation.

Exclusionary/Inclusionary Criteria. The eligibility requirements included a diagnosis of T2D or metabolic syndrome, aged 50-75 years, and low-active (defined as participating in regular exercise fewer than two days/week). Exclusionary criteria included: 1) failure of physician to provide medical approval for participation; 2) an inability to communicate in English; 3) involvement in another physical activity study; 4) leisure time physical activity more than 2x/week; and 5) failure to pass the Telephone Interview for Cognitive Status (TICS-M).

Gender and Minority Inclusion. Minority recruitment was emphasized for two reasons: 1) metabolic disease unequally affects minorities and 2) Central Illinois has a relatively low minority population. The goal was to recruit higher numbers of African Americans and Latinos than exist in the population. This sample includes 13.8% African American (12.7% in Champaign County), 2.4% Asian-Americans (9.4% in Champaign County), and 1.6% Latino (5.5% in Champaign County). Recruitment efforts were successful in reaching African Americans but were not as successful with Asian-Americans and Latinos.

Experimental Design

Study design was a two-armed randomized controlled exercise trial developed for individuals with T2D and metabolic syndrome. The intervention period was 8 weeks long with a four month follow-up; testing time-points were at baseline, month two, and month six. Additionally, self-efficacy was assessed at week two of the intervention. The intervention group received a targeted theory-driven, exercise behavior change intervention while the other group received a control condition by completing an online educational program about health, physical activity and T2D. The primary outcome was physical activity at month six. Neurocognitive evidence suggests that at least four months of physical activity is required to observe cognitive responses due to chronic physical activity (Colcombe & Kramer, 2003), so improvements in executive function were anticipated at month six.

The exercise intervention consisted of two main components: on-site and at-home. The on-site intervention involved four group workshops and on-site walking exercise. The group workshop content emphasized self-regulatory skill development and building self-efficacy. The exercise intervention was formatted in a titrated manner. The frequency of on-site exercise sessions decreased as the intervention period progressed with the goal of gradually teaching

participants to incorporate regular exercise into their daily life at home. Participants gradually built up to five 30+ minute bouts (150+ minutes) of exercise per week. Figure 3 illustrates exercise intervention content. Participants were taught to use a simple 5-point Likert scale for rating their perceived exertion—with '1' indicating very light and '5' working very hard. Their exercise prescription included ranges for target RPE starting around 2-3 in the first week and building to 3 -5. Participants were also taught how to use home logs as a self-monitoring tool.

The education group completed an eight-week online course covering topics related to general metabolic health: glucose; insulin; weight management; food and nutrition; physical activity; diabetic complications and eye, kidney, and foot care; stress management; and healthy aging. Each module contained educational videos and readings, a discussion question, and a weekly assignment. After study completion, education participants were offered a complimentary exercise consultation with an exercise specialist.

Measures

Health History and Baseline Demographics. Each participant completed a standard health history questionnaire. All current medications, including insulin, were recorded. Participants also completed a basic demographics form including age, gender/sex, income, education, race and ethnicity, marital status, etc.

Mental Status. As noted previously, the Telephone Interview of Cognitive Status (TICS-M) was used to screen for dementia and Alzheimer's disease. The TICS-M is a brief, 13 item questionnaire that can be delivered over the phone and screens for cognitive impairment. The TICS-M is less constrained by ceiling effect compared to the MMSE, thereby increasing utility. The maximum score on the TICS-M is 39 with a score below 21 being equivalent to a score

below 25 on the Mini Mental Status Examination. Individuals with scores of 21 and above were eligible to participate (de Jager, Budge, and Clarke, 2003).

Physical Activity. Physical activity was measured objectively via accelerometry at all three time-points. The Actigraph accelerometer (GT3X) is a small device which records movement in three dimensions. Participants were instructed to wear the activity monitor fastened with a belt provided on their non-dominant hip. Participants were instructed to wear the accelerometer during all waking hours, except for bathing or swimming, for seven full days. Participants recorded time and days the accelerometer was worn on a home log, which was used to verify wear-time. The activity data were checked for long periods of non-wear time (0's) and were validated with the criteria of: 1) at least 10 hours of wear time per day (Masse et al., 2005), 2) at least 3 days of valid data, and 3) a 60-minute interruption period (Copeland, 2009; Mailey et al., 2014). If there were more than 20,000 counts per minute the data were considered inaccurate (Masse et al., 2005). Activity data were collected in one-minute intervals (epochs), with the total number of counts for each day summed and divided by the number of days of monitoring to calculate average daily activity. Freedson cut-points for older adults were used to estimate time spent in sedentary, light, and moderate to vigorous physical activity (Freedson, Melanson, and Sirand, 1998). The software used for analyzing the accelerometer data was ActiLife 5.2 and Meterplus.

Activity was also recorded by intervention group participants in home activity logs. The outcome measure from the physical activity logs is minutes of activity per week. These self-reported data were collected during the 8 week intervention.

Metabolic Measures. Blood samples were collected at each time-point. All university and biohazard policies were strictly followed concerning safety, containment, sterilization of the

environment, disposal of equipment, and transportation of samples. Blood was drawn between 0700 and 0900 after a 10-12 hour overnight fast. Strict adherence to the schedule was enforced in order to avoid diurnal variation or other interfering factors.

Glucose regulation was measured to assess the efficacy of the intervention in improving metabolic parameters. Blood was tested for fasting glucose, fasting insulin, and glycosylated hemoglobin (HbA1c), which gives an idea of the extent of glucose dysregulation over time. The fasting blood glucose measurement was obtained directly after the blood draw with a glucometer. Samples, both intact and spun, were sent to the Translational Research Center on campus for HbA1c and insulin analyses. Additionally, the phlebotomist drew two extra tubes (3ml each), which was spun, aliquoted into serum and plasma samples, and frozen. Those samples are available for further analyses. The homeostatic model assessment (HOMA) was used to estimate insulin resistance from fasting glucose and insulin.

Anthropometric Measures. Height and weight was measured and BMI was calculated. Waist and hip circumferences were measured to calculate waist-to-hip circumference ratio as an estimation of abdominal obesity. Resting blood pressure and heart rate were also measured.

Neurocognitive Measures. Following the recommendations of Miyake et al. (2000), multiple measures of executive function were used to determine individual contributions of different processes. Specific measures were included to assess types of functioning that have been identified as vulnerable to metabolic disease, such as memory and prefrontal function. Computer-based and paper-and-pencil tasks were utilized.

Stroop. A modified Stroop task, a measure of attention and inhibition, (Erickson et al., 2007; Milhalm et al., 2002) consists of three trial types: congruent, neutral, and incongruent. The congruent condition contained words displayed in a color that matches the word of the stimuli

(e.g. BLUE in blue color) whereas the neutral condition contained words that were matched for the length and frequency of the color of the stimuli but not a color category (e.g. SHIP in blue color). The incongruent stimuli presented words which were in presented in a different color than the written word (e.g. BLUE in red color). The task of the participant was to identify the color the word was presented in. There were 48 trials of each condition randomly presented summing to a total of 144 trials. Participants were presented with different ordering of the trials at each time-point. Stimuli were presented upon response to previous trial so speed of task completion was dependent upon reaction time. Outcome variables included reaction times, accuracy and errors. A traditional interference cost variable was calculated by subtracting congruent from incongruent trials.

Trail Making Test. The Trail-making Test (Reitan, 1958, 1992) is a paper and pencil task designed to examine neurocognitive processes such as planning and switching. The task consisted of two parts: A and B. In part A, participants connected circles according to the number written within from 1 to 25, as quickly and accurately as possible. For part B, the circles contain numbers 1 to 13 and letters A to L. The participant's task was to connect the circles in sequential order alternating between numbers and letters. The Trail Making Test requires immediate recognition and reaction to the symbolic significance of numbers and letters, the ability to scan the page continuously, and flexibility in integrating the alpha-numerical sequence. The left hemisphere is largely responsible for language and symbols while the right hemisphere is more responsible for spatial orientation. The speed and efficiency of completing this task requires integration of both cerebral hemispheres and may reflect general adequacy of brain function.

A 5-trail variant of the trail making test, the Comprehensive Trail-Making Test (CTMT; Reynolds, 2002) was used. The first three trails were trail type A with varying degrees of difficulty determined by the number and placement of non-relevant circles. In the fourth trail test, some of the numbers were presented in word form and some in numeral form. The fifth and final trail test was trail B, which required alternating between numbers and letters. A cost score, reflecting cost of cognitive flexibility require for trail B (Salthouse et al., 2000), was calculated by subtracting average time taken to complete trails 1-3 (A) from trail 5 (B).

Flanker. A modified flanker paradigm task, where participants identified the orientation of a central arrow cue that is flanked by congruent (e.g. >>>>>) or incongruent (e.g. >><>>) arrows, was used to measure attention and inhibition. Participants responded to a row of arrows presented on the screen by pressing the key on the right side if the middle arrow pointed to the right or the key on the left side if the middle arrow pointed to the left. Half of the total trials (n = 100) were congruent and half were incongruent. This task tests ability to focus on relevant stimuli and ignore irrelevant stimuli, in other words inhibition. Proportional cost was calculated by subtracting congruent reaction time from incongruent reaction time and then dividing by congruent reaction time (Botvinick et al., 1999; Voss et al, 2010).

N-Back. A modified serial n-back task involving three consecutive phases was used. Each phase required the participants to discriminate between 5 distinct shapes: blue circles, green triangles, purple stars, red squares, and yellow crosses as the stimuli. In the first phase (0-back), participants were instructed to respond as quickly and accurately as possible with a right button press when the yellow cross appeared and with a left button press when any other shape appeared. In the 1-back and 2-back phases, participants were instructed to respond with a right button press if the current shape was the same as the previous trial (for the 1-back) or two trials

ago (for the 2-back). If the current shape was different, participants responded with a left button press. Each consecutive condition had 80, 79, and 78 trials, respectively. Accuracy and reaction time were measured and inverse efficiency (reaction time/proportion correct responses) calculated. Hits and correct reject trials were also identified to enable future secondary analyses using signal detection theory.

Spatial Working Memory. Spatial working memory was measured by average reaction time across three sets of a task developed by Greenwood and colleagues (2005). Participants were asked to focus on a crosshair for one second, after which one, two, or three grey dots appeared randomly on the screen for 500ms. Following this stimulus the crosshair re-appeared for a period of three seconds. Next, a red dot appeared on the screen in either one of the same locations as the previous black target dots (match condition) or at a different location (non-match condition). The participant had two seconds to determine whether the stimulus was a match or non-match by pressing one of two keys on the response pad. There were 40 trials of each of the conditions. Outcome variables included accuracy, reaction time, standard deviation of reaction times, errors and inverse efficiency for each condition (1-, 2-, and 3-dot) and overall.

Dual Task. Dual Task is a measure of task coordination (Bherer et al., 2005; Erickson et al., 2007). Two conditions were presented in which participants responded to one (single task) or two (dual task) stimuli. The single task trials involved the presentation of either a single letter (A or B) or number (2 or 3) stimulus whereas the dual task trials presented two stimuli, a letter and a number. Participants were instructed to press a corresponding key to each stimulus (A, B, 2, 3). In the dual condition, participants responded by pressing two corresponding keys. Outcome variables include single and dual reaction times and accuracies. A cost variable was calculated

by subtracting the single reaction time from the average of the dual reaction times. Accuracy cost was calculated with the following equation: 1 – dual response accuracy.

Psychosocial Assessments. Participants completed a questionnaire battery assessing self-efficacy and self-regulatory strategy use.

Self-efficacy. Several aspects of physical activity related self-efficacy were assessed. The Barriers-specific Self-Efficacy Scale (BARSE; McAuley, 1992), a 13-item questionnaire that measures beliefs in one's own abilities to exercise in the face of various types of barriers such as discouragement or bad weather, was used. Walking self-efficacy was measured relative to ability to 1) walk for a specific duration of time (40+ minutes) for the next month, two months, three months etc. (EXSE); 2) walk continuously at a fast pace for 5 minutes, 10 minutes, 15 minutes, etc. (SEW); and to adhere to regular (~5 days/week) walking exercise (LSE) (McAuley et al., 2009). All self-efficacy items were presented on a continuum from 0 to 100 with 0 representing "not confident at all" in personal ability to complete the task and 100 representing "completely confident" to complete the task. BARSE, SEW, LSE and EXSE showed excellent internal reliability (α = .96, .98, .99, .98 respectively).

Self-regulatory strategy usage. Self-regulatory strategy use specific to physical activity was measured by the 12-item Physical Activity Self-Regulation scale (PASR-12; Umstattd, Motl, Wilcox, Saunders, and Watford, 2009). Its subscales include the following domains: self-monitoring, goal setting, eliciting social support, reinforcement, time management, and relapse prevention. International consistency for subscales ranged from α = .72 to .92.

Procedures

Individuals responding to study advertisements were screened by telephone for all qualifying criteria, including the TICS-M. If individuals met all inclusionary criteria and remained interested in participation after hearing an explanation of the study and participation requirements, they were scheduled for an orientation and mailed a copy of the Institutional Review Board approved informed consent, a map to the research facilities, orientation documents and paperwork to be completed to acquire physician consent to participate. At the orientation, a power-point presentation explained the study goals and what participation entailed. Each individual was asked if they had read and understand the informed consent they were sent. If they had not had time to read it, another copy was provided to them and time given to read it and ask any questions. After a full explanation of the study and all questions had been addressed, participants were asked to sign the informed consent document and fill out a brief health history. Permission to contact their physician was obtained and they were scheduled for the baseline testing visits. Participants were also given an accelerometer to wear and a questionnaire packet to complete. Study research assistants facilitated obtaining physician approval to participate by contacting the doctors and faxing the appropriate documents, after collecting participant permission to do so. Physician consent was obtained before randomization.

The three testing visits included: 1) blood draw, 2) functional fitness testing and 3) neuropsychological testing. For the blood draw, participants were asked to fast overnight and scheduled to come between 7-9am. Water, juice, and fiber bars were provided for participants to consume after the blood draw. Functional fitness testing was completed on-site in the Exercise Psychology Lab at a separate time from the blood draw to ensure people were well-rested and

not-fasting. Anthropometric measures, including height and weight, blood pressure, resting heart rate, and waist/hip circumferences were collected at this visit.

All cognitive testing was scheduled in two-hour blocks and took place in a quiet, well-lit room in the main section of the Exercise Psychology Laboratory. Noise cancelling headphones and water were also provided. Each task was explained thoroughly with a practice run to assure understanding. STIM software was used for the Flanker, N-back, Stroop and Spatial Working Memory tasks. E-prime software was used for the Dual Task. The Trail Making Task was conducted with paper, pencil and a stopwatch. The order of the tasks was consistent for all participants and time-points. However each computer task had three run files with different trial order which were randomly counterbalanced across the three time-points. The accelerometer and questionnaire packet were collected at the cognitive testing visit. If participants had not finished wearing the accelerometer, they were given a stamped envelope to mail it back.

After all baseline data had been collected, participants were randomized into the exercise intervention or education group. Participants were notified by email and telephone as to group placement and the exercise intervention participants were sent schedules for the on-site walking and group workshop dates, times and locations. Five waves of 20-30 people were conducted to ensure appropriate group workshop size. For waves 2, 3 and 5, two group workshop times were scheduled per wave to accommodate participant schedules. The time of the on-site walking varied by wave to accommodate participant schedules and preferences. Waves 1, 2, 3, and 5 had morning sessions and waves 2 and 4 had evening sessions.

During week two, an additional, abbreviated questionnaire packet with self-efficacy measures was collected, in person from intervention participants and by mail from education participants. After the 8-week intervention period, all testing procedures were repeated. Again,

the same procedures were followed at month 6 testing. At the end of all data collection, the participants received personal results from the study and there was a drawing for 4 Amazon gift certificates, two to each group, valued at $50 for participant appreciation. Program evaluations were sent to participants at month two to evaluate participant satisfaction and gather suggestions/comments.

Data Analysis

Power Analysis. Initial sample size was based on: (a) data from previous estimations of change in physical activity across time (McAuley et al., 2000) using social cognitive predictors and (b) the expectation that subjects would be lost to attrition across the time of study. With the initial plan to retain 70 participants from a proposed 80, estimated power would have been sufficient, in excess of .90 to detect a conservative effect (i.e., small to medium changes in variation (.02 - .15)) in the primary outcome measure, physical activity, across time. Overall, it was proposed that a sample size of n = 80 would provide adequate statistical power for the proposed analyses. Moreover, this project was in nature a pilot study; therefore a smaller sample size was appropriate.

Quality Control and Data Checking. Data were entered and checked by trained research assistants. The quality of data was checked for missing and erroneous data by examining descriptive statistics and score ranges of all variables. Subsequently, all data were examined for violation of basic statistical assumptions (i.e., normality, multicollinearity, and homoscedascity) and transformed if necessary.

***Data Analyses*.** Data were checked for missing items, normality, outliers and errors. Descriptive analysis of the data was generated. Independent t-test was used to examine whether significant mean differences existed in demographic, health, physical activity, cognitive, and

self-regulatory strategy use between groups at all time-points. The self-regulatory self-efficacy model of behavior was analyzed with a path analysis using a covariance framework (objective 1).

Analyses pertaining to the first objective were conducted within a latent variable framework using *Mplus* statistical software package (version 6.0) with robust maximum likelihood estimation (Muthén & Muthén, 2010). Model fit was evaluated using multiple criteria [e.g. significant *p* value associated with $\chi 2$, comparative fit index (CFI) $\geq .95$, and the root mean square error of approximation (RMSEA) $\leq .08$] (Hu & Bentler, 1999). Measurement models were assessed for the latent constructs before they were entered into a theoretical structural model. The following variables were used as covariates: age, gender, income, and group.

A series of repeated measures ANOVAs was used to detect changes over time in: FBG, HbA1c, insulin resistance, self-efficacy, self-regulatory strategy use and cognitive performance (objective 2). Interactions and main effects were examined and effect sizes calculated. When baseline values differed by group, analysis of covariance (ANCOVA) was used to control for baseline values. Correlational statistics and multivariate regression analysis were used to explore predictors and determinants of change in main variables.

To test the efficacy of the REWinD intervention in increasing physical activity, compared to the education control condition, repeated measures analysis of variance was utilized. A 2 (condition) by 3 (time) repeated measures analysis of variance was used to determine whether the intervention was effective in increasing physical activity. Month 6 was the time-point of interest for physical activity. The analyses of all data associated with this study employed an intent-to-treat model, comparing the intervention to the education control group.

CHAPTER IV: RESULTS

Participant Characteristics and Retention

Baseline characteristics of the 116 participants who started the trial are displayed in Table 1. On average, participants were 62.8 ± 6.4 years old. The average HbA1c level at baseline was 7.11 ± 1.4. The generally used HbA1c diagnostic criterion for T2D is 6.5%. Average BMI was in the obese category with a value of 35.8 ± 6.4. About two-thirds of the sample were taking oral medications for diabetes, such as Metformin or Glyburide, and approximately a quarter of the sample was taking injectable insulin, such as Humalog or Lantus. The majority of the sample was female (64.7%), White (81.0%), and college graduates (54.8%). There were no significant differences between groups on any of the baseline demographic or disease variables. However, for BMI and HbA1c the exercise group trended towards higher values (p = .08). The majority (n = 99, 85.3%) of participants had been diagnosed with T2D; a small proportion (n = 17, 14.6%) had been diagnosed with metabolic syndrome.

A total of 308 individuals initially expressed interest in the study. Of these, 75 individuals were not eligible to participate and 108 individuals declined participation (total excluded n = 183). The remaining individuals (n = 125) attended an orientation, signed an informed consent, completed baseline testing, and were randomized. Nine individuals were unable to be contacted with randomization (n = 3), refused randomization (n = 2), or experienced new personal or family issues (n = 4) which prevented participation. A total of 116 individuals were randomized and started the trial. At post-intervention testing, 13 individuals were lost to follow up due to the following reasons: unable to contact (n =3), uninterested (n =2), new illness/diagnoses (n = 3), existing illness (n = 4), and family issues (n = 1). At the final, follow-up time-point (month six),

11 additional individuals were lost to follow-up due to the following reasons: unable to contact (n = 8), uninterested (n = 2), and existing illness (n =1). Overall, 24 people (20.6% of the initial 116 starting the program) were lost to follow-up and 92 individuals completed all three testing time-points (see Figure 4 for the CONSORT diagram).

Exercise intervention group adherence was sufficient. Mean group attendance was 81.4% and mean exercise attendance was 85.9%. Intervention participants completed exercise logs of their on-site and at-home exercise (n = 51 from those who completed intervention). Data from the exercise logs revealed that the average weekly time spent exercising was 158 ± 62.2 minutes. The percentage of missing data increased across the 8-week period as some individuals opted to discontinue the intervention but were still willing to come back for follow-up testing. Therefore the weekly means from the exercise logs represent the most adherent participants. Consequently, exercise log data were not used in analyses (see Table 2 for exercise log data missingness, weekly means and standard deviations).

Education group adherence was more difficult to track as analytics for individual website visits were not programmed. However, participant engagement in the discussion questions ranged from 27% to 62%. This is certainly an under-estimate due to the fact that participants reported two common reasons for not posting on the discussion board: 1) privacy concerns and 2) technological difficulty. Module views ranged from 112 views on Week 8 Module to 377 views on Week 1. In general, there was a trend towards less website engagement over the 8-week course. Table 3 provides an overview of education group website engagement.

A series of independent t-tests was used to determine whether participants who completed the study differed from those who dropped out following randomization on any demographic or baseline measures. Analyses revealed that participants who completed the trial

had higher income (t(117)=2.73, p<.05), lower BMI (t(123)=-2.94, p<.01), and lower glycosylated hemoglobin (t(123)=-2.14, p<.05). For the main analyses the sample (n = 116) who started the intervention was used.

Objective 1: Self-Regulatory Capacity & Physical Activity Model Results

A series of confirmatory factor analyses of each latent measure was first conducted to assess factor structure of latent constructs. *Self-efficacy* was represented by 1) BARSE, 2) LSE, 3) SEW and 4) EXSE. *Self-regulatory strategy use* was represented by the six subscales of the scale. *Memory cost* was represented by 1) one-dot spatial working memory inverse efficiency, 2) two-dot spatial working memory inverse efficiency, 3) three-dot spatial working memory inverse efficiency, 4) one-back inverse efficiency and 5) two-back inverse efficiency. *Cognitive flexibility cost* was represented by 1) dual task cost and 2) trail making task cost. Models for each of the latent constructs with four or more manifest variables fit the data well: *self-efficacy* (χ^2 = 91.647(6), p < .01, CFI = .981, RMSEA = .088, SRMR = .024), *self-regulatory strategy use* (χ^2 = 282.272(15), p < .01, CFI = .989, RMSEA = .054, SRMR = .033), and *memory cost* (χ^2 = 151.743(10), p < .01, CFI = .988, RMSEA = .055, SRMR = .052). The primary outcome of *physical activity* at month 6 was minutes of moderate to vigorous physical activity per day as measured by accelerometry. Baseline assessments included executive function and self-regulatory strategy use and self-efficacy was assessed at week 2 of the program. After confirming that the full measurement model, including all of the latent constructs, fit the data well (χ^2 = 1108.476(171), p < .01, CFI = .964, RMSEA = .046, SRMR = .075), testing of the hypothesized structural model was conducted.

Initially, a model (Model 1) with *memory cost* as the sole executive function construct was tested. Age, gender, group and income were included as covariates. Model 1 fit the data well (χ^2 = 200.779(147), p < .01, CFI = .948, RMSEA = .057, SRMR = .067). Consistent with hypotheses, there were significant direct effects of self-efficacy on physical activity, with marginal significance (β = .15, p = .09). Self-regulatory strategy use directly predicted both self-efficacy (β = .28, p < .05) and physical activity at month six (β = .21, p < .05). Baseline executive function was correlated with self-regulatory strategy use such that memory cost was negatively associated with self-regulatory strategy use (β = -.36, p < .01). There were several significant associations among the auxiliary covariates and model constructs. Older age was significantly associated with higher self-efficacy (β = .24, p < .05), more self-regulatory strategy use (β = .17, p < .05), higher memory cost (β = .19, p < .05) and less physical activity (β = -.22, p < .05). Lower income was also significantly associated with higher memory cost (β = -.47, p < .01). Being male was associated with higher physical activity (β = .27, p < .01). Exercise group assignment was associated with higher self-efficacy (β = -.35, p < .01; exercise group coded as '1', education coded as '2') and increased physical activity at month six (β = -.22, p < .05). An indirect effect from exercise group to physical activity via self-efficacy was marginally significant (β = -.06, p = .08). Overall, this model predicted 28.4% of the variance in physical activity and 31.2% of the variance in self-efficacy (see Figure 5).

Considering the relationship between both memory and cognitive flexibility and T2D, another structural model including *cognitive flexibility cost* as an additional cognitive latent construct was tested. Again, the data fit the model well (χ^2 = 231.272(178), p < .01, CFI = .951, RMSEA = .052, SRMR = .065). Self-efficacy (β = .16, p = .07) and self-regulatory strategy use (β = .21 p < .05) directly predicted physical activity. Self-regulatory strategy use directly

predicted self-efficacy (β = .28, $p < .01$). Memory cost (β = -.33, $p < .01$) and cognitive flexibility cost (β = -.17, $p = .06$) both negatively correlated with self-regulatory strategy use and positively with each other (β = .45, $p < .01$).

Again, older age was associated with higher efficacy (β = .23, $p < .05$), more self-regulatory strategy use (β = .17, $p < .05$), higher memory cost (β = .19, $p < .01$), and lower levels of physical activity at month six (β = -.22, $p < .05$). Being male (β = .35, $p < .01$) and having lower income (β = -.32, $p < .05$) were associated with higher cognitive flexibility cost. Being male was also associated with higher physical activity at month six (β = .25, $p < .05$). Lower income was also associated with higher memory cost (β = -.47, $p < .01$). Group itself had only a marginal effect on physical activity (β = -.14, $p = .08$) but being in the intervention group predicted higher self-efficacy (β = -.36, $p < .01$). Again group marginally predicted physical activity via self-efficacy (β = -.06, $p = .07$). Model 2 predicted 32.3% of the variance in physical activity and 28.9% of the variance in self-efficacy (see Figure 6).

Due to power constraints with the addition of any further latent executive function variables, the final model was tested with executive function as manifest variables, including the following: dual task cost, n-back one inverse efficiency, trail making test cost, Stroop interference cost, and flanker proportional cost. The use of manifest, compared to latent, executive function variables increased statistical power, which allowed for the addition of baseline physical activity as an auxiliary covariate. The data fit the model (Model 3) well (χ^2 = 178.357(144), $p < .05$, CFI = .946, RMSEA = .046, SRMR = .067). Self-regulatory strategy use directly predicted self-efficacy (β = .26, $p < .05$), which in turn directly predicted physical activity (β = .18, $p < .05$). N-back inverse efficiency directly predicted self-efficacy (β = -.14, $p <$

.05) and trended towards predicting physical activity indirectly through self-efficacy (β = -.03, *p* = .11). Dual task cost* (β = -.13, *p* < .05); trail making test cost (β = -.14, *p* < .05); Stroop interference cost* (β = -.11, *p* < .05); and flanker proportional cost, with marginal significance (β = -.18, *p* = .07) directly predicted physical activity at month six.

Older age was associated with higher efficacy (β = .28, *p* < .05), more self-regulatory strategy use (β = .24, *p* < .05), higher trail making test cost (β = .21, *p* < .01), and higher Stroop proportional cost (β = .18, *p* < .05) but was not associated with lower levels of physical activity at month six. Being male was associated with higher dual task cost (β = .37, *p* < .01) and n-back inverse efficiency (β = .20, *p* < .05), but was not associated with physical activity at month six. Having lower income was also associated with higher dual task cost (β = -.24, *p* < .05) and higher trail making test cost (β = -21, *p* < .05). Group itself had only a marginal effect on physical activity (β = -.10, *p* = .09) but being in the intervention group predicted higher self-efficacy (β = -.35, *p* < .01) and indirectly predicted physical activity through self-efficacy (β = -.06, *p* < .05). Higher baseline physical activity was associated with more self-regulatory strategy use (β = .25, *p* < .05), lower dual task cost (β = -.17, *p* < .05), lower n-back inverse efficiency cost (β = -.28, *p* < .01), and lower Stroop interference cost (β = -.18, *p* < .01). Baseline physical activity additionally predicted approximately 23% of the variance in physical activity at month six (β = .59, *p* < .01). Model 3 predicted 32.9% of the variance in self-efficacy and 56.7% of the variance in physical activity (see Figure 7).

* Exhibited statistical suppression effects in the Mplus output where relationships initially appeared positive. Further investigation revealed negative directionality in the correlation matrix. Suppression effect occurs when inverse path relationships between auxiliary variables and inverse path relationship between manifest variable and outcome variable cancel each other out to result in a spurious positive relationship (MacKinnon, Krull, & Lockwood, 2000).

Objective 2: Changes in Cognitive Function, Self-Regulatory Strategy Use, Self-efficacy, & Metabolic Parameters By Group

There were no group effects on any of the cognitive function variables. Several cognitive variables indicated time effects where performance increased slightly across the study period: Stroop reaction time interference cost [$F(1,91) = 5.251$, $p < .05$, $\eta^2 = .055$], flanker accuracy proportional cost [$F(2,90) = 4.756$, $p < .05$, $\eta^2 = .096$], two-back inverse efficiency [$F(2,88) = 15.158$, $p < .01$, $\eta^2 = .254$], and three-dot spatial working memory inverse efficiency [$F(2,90) = 4.077$, $p < .05$, $\eta^2 = .083$]. None of these time effects remained significant with the addition of age, gender, and income as covariates. Flanker reaction time proportional cost, dual task cost, zero-back inverse efficiency, one-back inverse efficiency, Stroop accuracy interference cost, one-dot spatial working memory inverse efficiency, and two-dot spatial working memory inverse efficiency showed no changes.

Repeated measures analysis of variance in self-regulatory strategy use revealed both time [$F(2,88) = 29.127$, $p < .001$, $\eta^2 = .40$] and group by time [$F(2,88) = 14.021$, $p < .001$, $\eta^2 = .24$] effects. The time by group interaction was quadratic in nature [$F(12,77) = 7.517$, $p < .05$, $\eta^2 = .54$] such that self-regulatory strategy use increased substantially in the exercise group at month two and then declined slightly at month six. Self-regulatory strategy use in the education group trended towards a slight increase at month six ($p = .09$). Figure 8 shows trajectories of self-regulatory strategy use by group. Table 4 displays short- and long-term intervention effects on self-regulatory strategy use.

Trajectories of self-efficacy across the trial period showed significant group by time differences. An overall repeated measure MANOVA (2 x 4) with SEW, LSE, BARSE, and EXSE representing self-efficacy revealed both a significant time effect [$F(12,77) = 7.517$, $p <$

.001, η^2 = .539] and group by time effect [F(12,77) = 2.322, p < .05, η^2 = .266]. Subsequently, each efficacy measure was analyzed separately using repeated measures analysis of variance (Figure 9). Additionally, a series of within group paired t-tests was used to determine short- and long-term intervention effects and calculate effect sizes for each efficacy measure (see Table 5).

The trajectory of SEW showed a quadratic pattern by time and group [F(1,88) = 5.864, p < .05, η^2 = .06], where the exercise group increased more from baseline to week two, continued to increase to month two and, despite a small decline, remained higher compared to the education group at month six. As baseline values were higher in the intervention group (p < .05), a series of ANCOVAs was conducted controlling for SEW baseline value. Results indicated significant effects of group at week two [F(1,16.512) = 6.992, p < .05, η^2 = .30], month two [F(1,13.388) = 22.622, p < .01, η^2 = .63], and month six [F(1,10.482) = 13.804, p < .01, η^2 = .57] (see Figure 9 for graphs of SEW trajectory and SEW trajectory adjusted for baseline).

Trajectories of LSE differed by group [F(3,86) = 3.323, p < .05, η^2 = .10]. Analysis of covariance (controlling for baseline values) indicated group differences at week two, month two, and month six, favoring increases over time in the intervention group. LSE linearly declined in the education group. In the exercise group, LSE increased from baseline to month two and then declined at month six to baseline value.

For BARSE, results from the repeated measures ANOVA revealed significant time [F(3,86) = 11.525, p < .01, η^2 = .29], and time by group effects [F(3,86) = 2.732, p < .05, η^2 = .05]. The time by group interaction indicated a linear trajectory with marginal significance [F(1,88) = 3.748, p = .06, η^2 = .04]. Further examination of these results revealed similar patterns in both groups but a larger increase in the intervention group by week two followed by a gradual decrease compared to the education group; baseline values for BARSE did not differ by group.

EXSE showed a significant time effect [$F(3,86) = 5.297$, $p < .01$, $\eta^2 = .16$] and a marginally significant cubic group effect [$F(1,88) = 3.437$, $p = .06$, $\eta^2 = .06$]. EXSE values in the exercise group were higher at baseline ($p < .05$), week two ($p < .01$), month two ($p < .01$), and month six ($p < .01$). Because of baseline differences, a series of ANCOVAs was conducted to estimate intervention effect while controlling for baseline values of EXSE. Results indicated no significant contribution of group at week two and month six. At month two, the group by efficacy interaction was trending towards significance with the exercise condition displaying higher efficacy values [$F(11,53) = 1.714$, $p = .09$, $\eta^2 = .26$] (see Figure 9, Table 5).

Analysis of trajectories of glycosylated hemoglobin (HbA1c) by group indicated an earlier effect than anticipated, which was not sustained. Overall, repeated measures analysis of variance indicated neither a time nor time by group effect. However, within-subjects analyses revealed a small quadratic group effect on HbA1c trajectory [$F(1,90) = 4.222$, $p < .05$, $\eta^2 = .05$]. As HbA1c was higher in the exercise group at baseline ($p < .05$), a series of ANCOVAs controlling for baseline HbA1c were conducted (see Figure 10). Within group paired t-tests revealed a slight decrease in HbA1c in the intervention group at month two, which was not sustained at month six. Estimation of insulin resistance using the HOMA ratio of fasting glucose and insulin showed no change across time. Fasting blood glucose decreased over time with no group effect [$F(2,88) = 3.817$, $p < .05$, $\eta^2 = .08$] (see Figure 11).

The final prediction of hypothesis two was that improvements observed in the intervention group would be related to changes in physical activity. Change in minutes of MVPA per day (accelerometer) from baseline to post-intervention significantly correlated with self-efficacy and strategy use at month two and month six (see Table 7 for partial correlation results). A series of regression analyses, controlling for age, gender and income, and baseline value

revealed that change in physical activity across the intervention period (accelerometer minutes of MVPA/day) significantly contributed to self-efficacy (see Table 8) and self-regulatory strategy use (see Table 9) at month two and month six. None of the physical activity variables predicted HbA1c at post-intervention or follow-up testing. However, in the intervention group, attendance was correlated with change in HbA1c from baseline to post-intervention (r = .334, p <.05) such that those who had higher attendance had higher decreases in HbA1c.

Objective 3: Efficacy of the Intervention in Increasing Physical Activity

The third objective was to determine if a short, theory-driven physical activity intervention would increase physical activity levels in older adults with T2D. The hypothesis that increases in physical activity would be observed post-intervention and sustained at follow-up in the intervention group compared to the education control was partially supported. The results from the repeated measures (2 x 3) ANOVA predicting trajectory of minutes of moderate-to-vigorous physical activity per day measured by accelerometer indicated an overall time by condition interaction [$F(2,83) = 5.777$, $p < .05$, $\eta^2 = .12$] while controlling for age, gender, and income. Within subjects analysis revealed similar results [$F(1.644,138.08) = 7.428$, $p < .01$, $\eta^2 = .08$] (using Greenhouse-Geisser estimation, as the dependent variable was not normally distributed). Further evaluation of these results revealed a quadratic trajectory for the accelerometer by group interaction [$F(1,84) = 9.206$, $p < .01$, $\eta^2 = .10$] where a large increase was observed at month two, in the exercise group, followed by a decline at month six. On average, intervention participants increased from approximately 9 minutes per day of moderate-to-vigorous physical activity to 19 minutes a day at month two declining to 11 minutes a day at month six. On average, education participants maintained activity level around 7 minutes per day

across all time-points (see Figure 12). Activity level by group was significantly different at month two and month six (see Table 9 for means and effect sizes by group and time-point).

Participant Program Evaluation

Participant program evaluations revealed that the majority of participants were satisfied with their experience. In the education group (n = 36), 27.8% were *very satisfied,* 55.6% were *satisfied,* and 16.7% were *neither satisfied nor dissatisfied* with the overall program. In the exercise group (n = 43), 67.4% were *very satisfied*, 30.2% were *satisfied*, and 2.3% were *neither satisfied nor dissatisfied* with the overall program. The most highly rated aspect of participation for both groups was the "REWinD Team". The lowest rated aspect of participation was "Testing Experience". Intervention participants indicated that encouragement (32.4%), social reinforcement (10.8%), on-site exercise (29.7%) and the group workshops (10.8%) were the most helpful intervention components and parking (5.3%) and paperwork/testing (31.6%) were the least helpful components. Education participants mentioned the videos (13.5%) and course content (56.8%) as the most helpful components and being alone (2.7%), already knowing the material (10.8%), and testing (13.5%) as the least helpful. All of the intervention participants said they would recommend REWinD to a friend. Of the education participants, 68.6% said they would definitely recommend REWinD to a friend and 28.6% said they might recommend REWinD to a friend. In the process evaluation, participants mentioned that they believed the REWinD intervention was too short and titrated too quickly to allow for substantial behavior change. Their feedback is useful information for the adjustment of the REWinD intervention in future research.

CHAPTER V: DISCUSSION

Overview of Findings

This pilot study proposed to test a model of physical activity adherence that incorporated both social cognitive and neurocognitive perspectives of physical activity behavior in older adults with T2D. Overall, the results provide some support for the hypothesis that self-efficacy, self-regulatory strategy use and specific executive functions are determinants of physical activity in older adults with T2D. These findings are important given the cognitive impairments associated with T2D and the high self-regulatory demands of the disease. Self-regulatory failure has been implicated in many societal and health issues (Bauer & Baumeister, 2011) and self-management is crucial to the maintenance of health (Bandura, 2005). A better understanding of self-regulatory capacity is crucial to explaining, predicting, and influencing health behavior.

Older adults with T2D have low levels of physical activity despite the known health benefits. The REWinD Trial results provide some preliminary insight as to why physical activity adherence may be more difficult in this population, underscoring the importance of integrating neurocognitive and social cognitive perspectives in behavioral interventions. This pilot study also provides evidence that a short, 8-week physical activity intervention leads to small improvements in physical activity levels in older adults with T2D both post-intervention and four months later, compared to an education control group. These findings warrant a true efficacy trial to test whether effects can be replicated.

Objective 1: Self-Regulatory Capacity Model of Physical Activity

The primary hypothesis was partially confirmed by the data. The proposed model integrated social cognitive and neurocognitive perspectives of physical activity behavior. Theoretically, self-regulatory capacity encompasses both the outward skills or strategies and the underlying cognitive processes involved in self-control. From a social cognitive perspective, self-regulatory strategy use involves the ability to effectively utilize a variety of strategies such as goal-setting, self-monitoring, rewards, intention implementations, and relapse prevention. From a neurocognitive perspective, regulation integrates a complex interaction between regions of the prefrontal cortex and other brain structures such as the anterior cingulate cortex, hippocampus, amygdala, and parietal lobes. Together, self-regulatory capacity involves cognitive control and a developed arsenal of self-regulatory strategies.

As the understanding of the connection between T2D and specific executive functions is still unclear, these analyses were exploratory in nature to determine specific aspects of executive function that may contribute to physical activity behavior. Memory deficits appear to occur first in disease progression; the proposed self-regulatory adherence model was tested first with memory as the sole latent cognitive function construct. This model suggests that memory function was directly related to self-regulatory strategy use, which in turn was related to both self-efficacy and physical activity.

Memory cost was inversely related to self-regulatory strategy use, supporting the theoretical cognitive underpinnings of self-regulatory strategy use. Largely, the working memory literature from cognitive psychology and the psychological literature on self-regulation have failed to overlap. More recently, some research has integrated perspectives. Hofmann and

colleagues (2011) argue that the mechanisms underlying working memory are fundamentally related to those involved in self-regulatory goal pursuit. Active and accurate representation of goal-relevant information is essential to successfully accomplishing personal goals. Goals involve a mental representation of the desired end state and, often, a representation of the means by which to achieve them (Kruglanski et al., 2002; Miller & Cohen, 2001). Without a clear representation of the goal, attempts at self-regulation are directionless and prone to failure. Self-monitoring may also be dependent on working memory as it involves regular context-relevant, flexible updating of goal-representations. Future research on memory function in older adults with T2D would benefit from including tasks of prospective memory as remembering glucose testing and medication administration at the appropriate time is crucial for disease control.

Being in the intervention group significantly predicted increased self-efficacy, starting at week two, and physical activity six months later. This is not surprising given the social cognitive nature of the intervention and the literature establishing self-efficacy as an important construct for behavior change (Bandura, 2004; McAuley & Blissmer, 2000). Additionally, it is an encouraging finding as building self-efficacy may be more feasible than remediating disease- or age-related impairments in cognitive function. Self-efficacy is a consistent determinant of physical activity behavior and is especially important during the early adoption phase of behavior change. Not only does self-efficacy for physical activity predict physical activity but it is affected by past physical activity experiences. These data support previous findings that exposure to exercise programs increases efficacy (McAuley & Blissmer, 2000). The reciprocal relationship of physical activity and self-efficacy is evident in the results from REWinD. At the beginning of the program, intervention participants were introduced to physical activity in a

supervised, encouraging environment. The exercise group experience led to higher self-efficacy levels two weeks later and higher physical activity six months later.

In the second model, an additional executive function construct related to T2D, cognitive flexibility, was included. The dual and trail making tasks measure participant ability to switch between mental sets and be flexible in performing simultaneous functions. With the addition of cognitive flexibility to the model, relationships among model constructs remained relatively similar. The model indicated associations among memory, cognitive flexibility and self-regulatory strategy use. Being in the intervention group significantly predicted higher levels of self-efficacy and indirectly predicted physical activity through self-efficacy. Theories of self-regulatory capacity indicate that impairments in cognitive flexibility may significantly disrupt individual ability to self-regulate at a conscious, goal-directed level. Executive functions serve a critical higher-level role in behavior regulation and act as a primary mechanism of effortful self-control.

The hypothesized model is only partially supported by these two models. Despite associations among memory and cognitive flexibility with self-regulatory strategy use, the latent cognitive function variables did not directly, or indirectly, predict self-efficacy or physical activity. However, these models indicate that specific types of executive function (i.e., working memory and cognitive flexibility) were associated with greater use of self-regulatory strategies. Due to the temporal positioning of executive function and self-regulatory strategy use at baseline, it is impossible to determine directionality from these data. It is possible that individuals with high working memory and flexibility function were naturally inclined towards self-regulatory activities such as goal-setting, planning, and incentivizing. However, it could also

be that self-regulatory behaviors, or engagement in activities that require self-regulatory strategy use (such as work or physical activity), may improve, or sustain, brain function in older adulthood.

Due to sample size issues resulting in model non-convergence with the addition of any more latent constructs, manifest variables of executive function measures were used in a final model to incorporate inhibition-related tasks in addition to memory and flexibility. Switching to manifest variables also allowed for enough statistical power to include baseline physical activity as a covariate.

The final model indicated that executive function tasks relating to inhibition and flexibility directly predicted physical activity six months later. Memory performance predicted self-efficacy at week two and trended towards an indirect effect on physical activity through self-efficacy. The addition of baseline physical activity to the final model is important to consider. As it has been established that physical activity influences various executive functions, it is important to control for previous physical activity in the modeling of cognitive effect on physical activity adherence. Baseline physical activity alone accounted for over twenty percent of the variance in physical activity at month six, which indicates that the amount of variance in physical activity accounted for by self-regulatory strategy use, self-efficacy and executive function is similar to the previous models. As expected, baseline physical activity was also associated with several of the executive function tasks. This model suggests that, while controlling for baseline physical activity levels, specific executive functions directly predict physical activity adherence in older adults with T2D. These results underscore the importance of integrating both

motivational and cognitive aspects of behavior change as determinants of physical activity and as sources of self-efficacy information.

The final model, again, only partially supports the hypothesized self-regulatory physical activity adherence model. While these analyses were based on McAuley and colleagues (2011) integration of social cognitive and neurocognitive perspectives of physical activity behavior, several differences must be noted. The originally hypothesized model predicted that executive function and self-regulatory strategy use would predict physical activity indirectly through self-efficacy. Results indicated that of the executive function manifest variables, only working memory operated through self-efficacy, while the other tasks directly predicted physical activity. Several differences in study design may have contributed to these model dissimilarities. McAuley, Mullen and colleagues (2011) examined adherence in a sample of healthy older adults, all of whom received a physical activity intervention, over the course of twelve months. In the REWinD Trial, only half of the participants received a physical activity intervention. Given the group effect on self-efficacy, one could theorize that possibly the role of self-efficacy is more prominent in individuals who are actively involved in physical activity behavior change. Social cognitive theory presents efficacy information as specifically important during the adoption phase of behavior change. The fact that half of the sample in REWinD was not attempting physical activity behavior change could account for some of the model incongruences compared to McAuley's findings. Another possible explanation is that results from REWinD indicate shorter term adherence, with the primary physical activity outcome at month six, compared to McAuley and colleagues' trial which examined physical activity behavior over the course of an entire year. The study population presents a final possible explanation for the observed direct effects of executive function on physical activity. Executive function may be a more important

determinant of physical activity adherence in populations who experience marked cognitive impairments. It is impossible to support this hypothesis from these data, as there was no comparison group of non-diabetics. Statistical power is also limited in the REWinD trial, which may have made the detection of subtle, indirect effects more difficult.

These results provide some preliminary evidence that physical activity adherence may be more difficult for populations, such as older adults with T2D, who experience cognitive impairments. Naturally, more systematic research is necessary to establish these findings and develop interventions specifically targeting social cognitive constructs and executive function. Findings from this pilot trial do support the integration of neurocognitive and social-cognitive paradigms of behavior—that biological and cognitive perspectives are crucial to understanding self-regulated behavior (Bandura, 1997).

Objective 2: Trajectories of Social Cognitive and Health Variables across Time

Contrary to hypotheses, there were no intervention effects on executive function variables. However, results indicated slight improvements in some of the executive function measures, which most likely reflect practice effects. The hypothesis that executive function would show improvements in the intervention group at month six was ambitious considering the fact that this trial was designed to test adherence to physical activity, rather than the impact of regular physical activity on cognitive functioning. It is likely that the dose of aerobic exercise during the study period was too low and variable to result in changes in executive functioning. Unfortunately, it is impossible to make conclusions from these data about whether physical activity could be a viable intervention for remediation of the metabolic-cognitive syndrome.

As hypothesized, self-regulatory strategy use increased in the intervention group at month two and, despite some declines at month six, remained higher compared to the education group. Self-regulatory strategy use is crucial to adherence of goal-directed behavior. Behavior change, such as starting physical activity, is inherently goal-directed and cannot rely on habitual responses but instead must involve the development and use of self-regulatory skills (Bandura, 2005). Although self-regulatory strategy use among intervention participants declined at month six, they indicated that they still used these skills significantly more at the follow-up compared to baseline. These findings are as expected given the group workshop content emphasized goal-setting, planning, home log completion, reinforcement, and relapse prevention.

The intervention had its strongest effects on self-efficacy. The intervention group experienced higher self-efficacy, compared to the education group, in all four types of efficacy assessed with walking self-efficacy showing the largest group effect. The largest increase in walking self-efficacy was observed at week two of the intervention, when intervention participants had not yet started walking on their own. At the start of a program, participants can experience a boost of encouragement, motivation, and confidence. Walking self-efficacy increased between baseline and month two which was followed by a small decline at month six. Comparatively, walking self-efficacy did not change in the education group across the study period. The walking self-efficacy results from this pilot trial mirror those from McAuley, Mailey and colleagues (2011), who found that walking self-efficacy increased at the beginning of a physical activity program and then exhibited slight declines six months later. Considering the contribution of past experience to self-efficacy ideation, the on-site walking component of the behavioral intervention was likely crucial to the increase in walking self-efficacy.

The results from the remaining three self-efficacy measures were not quite as strong but remained in favor of the intervention group. Exercise self-efficacy increased in both groups at week two. In the intervention group, exercise self-efficacy continued to increase to month two and then declined during the follow-up period. The fact that the intervention group started with higher levels of exercise self-efficacy makes the results more difficult to interrupt. However, after controlling for baseline values, efficacy remained significantly higher in the intervention group post-intervention. Exercise self-efficacy levels for both groups at follow-up were not significantly different from baseline levels.

In the case of barriers efficacy, efficacy beliefs peaked at week two. At week two, the intervention participants were still benefiting from social support and social modeling from their cohort and research staff and had yet to attempt exercise independently. Barriers self-efficacy declined thereafter, presumably due to participants experiencing more barriers as they started integrating physical activity into their lives without the structured on-site program. When required to exercise independently, and then subsequently losing contact with the research team, efficacy decreased. Despite declines in self-efficacy by month six, efficacy levels in the intervention group were higher than those in the education group at month six. For lifestyle self-efficacy, the exercise group maintained levels of efficacy beliefs while the education group showed linearly declines in efficacy. It appears that participation in a physical activity intervention mitigated declining lifestyle self-efficacy. Overall, these data suggest that being in the intervention group had significant, positive effects on self-efficacy.

Participating in physical activity interventions does not guarantee improvements in exercise self-efficacy (Hughes et al., 2004; McAuley et al., 2003; Moore et al., 2006). Indeed,

McAuley and Mihalko (1998) suggest that sedentary older adults may not have enough salient experience to accurately formulate beliefs of exercise self-efficacy which may explain declines in self-efficacy during program participation. McAuley, Mailey and colleagues (2011) found support for this hypothesis such that older adults appeared to overestimate exercise efficacy before starting a physical activity program, which was followed by a lower efficacy adjustment three weeks later after actual exposure to regular physical activity. Contrary to those findings, these data indicate an increase in efficacy in the physical activity group at week two. It is possible that assessing efficacy at week two was too early for the excitement of a new program to have faded. In addition, the REWinD trial differed in nature from the trial in McAuley and colleagues' research. The emphasis on learning self-regulatory strategies and boosting self-efficacy in the REWinD group workshops may have been factors related to observed increases in self-efficacy.

Despite the primary purpose of this study being the examination of the effects of self-regulatory capacity on physical activity behavior, the second part of objective two was to determine whether effects from the intervention on physical activity influenced trajectories of self-efficacy and self-regulation. The hypothesis that physical activity would predict improvements in both self-regulatory strategy use and self-efficacy was supported. Change in physical activity from baseline to post-intervention predicted self-regulation and self-efficacy at post-intervention and follow-up. Given that past experience is a source of self-efficacy information, participating in a supportive physical activity program could be expected to boost self-efficacy for physical activity. The finding that physical activity increased self-regulatory strategy use is not surprising, but is important given the central role of self-regulatory capacity in behavioral control. It is possible that effects of physical activity on self-regulatory capacity could

operate through: 1) the impact of physical activity on brain structure and function and 2) practice effects of physical activity-related self-regulatory strategy use. These findings question directionality. The reciprocal relationship between self-efficacy and physical activity has been previously discussed. However, the directionality of the relationship between physical activity and self-regulatory capacity remains somewhat unclear. It may be that self-regulatory capacity is both a determinant and consequence of regular physical activity behavior.

It was also hypothesized that metabolic parameters, such as glycosylated hemoglobin, fasting blood glucose, and insulin resistance would show physical activity-related improvements at six month in the intervention group. This hypothesis was partially supported, but earlier than anticipated. The intervention group showed a small decline in HbA1c at month two. Some intervention participants experienced marked improvements in HbA1c over the intervention period. Anecdotally, a handful of participants reported lower HbA1c levels than they had seen in over five years. These results were somewhat surprising considering that HbA1c is an estimate of chronic blood glucose over the last three months. The contraction-mediated glucose uptake involved in physical activity is effective at lowering blood glucose, even in the presence of insulin resistance. Recently, Umpierre and colleagues (2011) conducted a review assessing efficacy of physical activity and exercise RCTs in decreasing glycosylated hemoglobin in adults with T2D. Structured exercise training, whether aerobic, anaerobic, or both, was associated with -.67% weight mean difference in HbA1c compared to control condition. Although the intervention effect observed from REWinD was smaller, the intervention period, at eight weeks, was at least three weeks shorter than any of the previously conducted exercise/physical activity trials targeting metabolic health, which averaged around approximately 30 weeks in program duration. Umpierre and colleagues' meta-analytic review indicated that structured exercise or

physical activity programs were more effective in decreasing HbA1c than programs focused on physical activity education and advice. The results presented herein corroborate those findings as the education participants, who received advice and education about physical activity, did not experience any mean changes in HbA1c. Moreover, intervention program attendance significantly correlated with change in HbA1c such that those who attended more on-site walking sessions and group workshops experienced more decline in HbA1c. However, the small magnitude of decrease may be within the error range of the assays.

However, intervention effect on HbA1c dissipated by month six. The increase in HbA1c in the intervention group to baseline levels at month six may be related to insufficient length of the intervention or to lower volume of physical activity during the study follow-up period. These results indicate that physical activity program participation may have effects on HbA1c earlier than previously thought. The fact that change in HbA1c did not correlate with change in physical activity warrants caution in the interpretation of the small group effect on HbA1c at month two.

There were no time or group effects on insulin resistance, which is likely due to the high variance involved in HOMA estimation of insulin resistance. Fasting blood glucose exhibited only a time effect within a general downward trajectory. It is possible that the decline in fasting blood glucose over time is due to drop-out as seven participants dropped out at month two and one at month six due to new or existing illness (that may have been related to diabetes). However, blood glucose is highly variable and considered an inaccurate and inconsistent stand-alone measure for metabolic health.

Objective 3: Intervention Effects on Physical Activity

The hypothesis that the intervention would be effective at increasing physical activity levels was partially supported by the data. The accelerometer results indicated intervention participants more than doubled minutes/day spent in moderate-to-vigorous physical activity by month two. However, intervention group physical activity declined from month two to month six. The intervention was successful at increasing physical activity both at month two and at month six, compared to the education control. It was not successful at maintaining gains in physical activity from month two to month six. These results suggest that the REWinD intervention may not be effective in increasing long-term physical activity adherence. The intervention period may have been too short for long-lasting behavior change to occur. Adoption of new complex behaviors, such as physical activity, can take as long as six months before more habitual, automatic mechanisms sustain the behavior. Additionally, the quick withdrawal of communication with the research team, by week eight, may have been too fast for some participants. It would be beneficial to test the inclusion of follow-up support, maybe through phone-calls or social media, in future testing of the REWinD intervention.

However, these findings are encouraging given the brevity of the intervention compared to trials such as the Diabetes Prevention Program and the Look AHEAD. These data support the idea that a brief, titrated intervention can increase short-term physical activity adherence in older adults with T2D.

Strengths and Limitations

This study has a number of strengths. First, it was a randomized controlled exercise trial; the first to consider cognitive function as a determinant of physical activity adherence in older

adults with T2D. The topic of this study is critical to public health as older adults are the fastest growing segment of the population and metabolic disease is extremely common in older-adulthood with the potential to result in considerable personal, family, and societal burden. The REWinD pilot trial was also the shortest physical activity intervention to-date, that we are aware of, in older adults with T2D. Results indicated that a brief physical activity program was successful in eliciting small increases physical activity four months later. This study presents a potentially effective lifestyle intervention for older adults with T2D that requires fewer resources compared to larger diabetes trials previously conducted. The titrated, intervention design may be more feasible for public health, medical, or community health professionals to replicate.

Considering the sample population, retention was satisfactory, with 88.8% completing post-intervention testing and 79.3% completing the six-month follow-up testing. Attendance to group workshops and on-site exercise was very high in those participants who completed the intervention period.

The use of objective neuropsychological and physical activity measures strengthens this research. Some of the previous research in T2D has relied on cognitive measures that are in nature screening tools, such as the Mini Mental State Exam, or tested cognitive function in only one neuropsychological domain. Additionally, the use of accelerometry allows study conclusions about the intervention efficacy to be objective.

The limitations of the present study must also be acknowledged. The study sample was fairly homogeneous, particularly in regard to socioeconomic status. Over half of the participants were college graduates with nearly a quarter having an advanced degree. The majority (67.2%) indicated that their annual household income was above $40K. Unfortunately, > $40K was the highest income category so it is impossible to further dissect the spread of participant income.

However, income was included in all of the analyses as a covariate because of the skewed nature of the sample population. The sample was not diverse considering ethnicity; however, the percentage of participants who were African American (13.8%) was higher than the county population percentage (which was 12.7% in 2012). The percentage of Asians in the sample was low, partially due to the low percentage representation in Champaign County (5%) and partially due to low rates of T2D in Asians compared to Whites or African Americans. The fact that speaking English fluently was an inclusion criterion for study participation resulted in lower reach to Latino and Hispanic individuals. Future research would warrant testing this intervention in Spanish in order to reach more of the Latino/Hispanic population who are disproportionately affected by T2D. Additionally, analyses revealed that participants who completed the trial had higher income, lower BMI, and lower glycosylated hemoglobin compared to those who dropped out. Individuals who participate in on-site trials, such as REWinD, tend to be healthier and have more resources (enabling them to drive to campus, etc.) compared to the general population. These findings underscore the importance of future research with increased reach. However, REWinD was a pilot, efficacy study in nature.

The education control group presents a study limitation. An education group provides a better comparison than usual care but was not a true attentional control given that education participants did not interact with each other or with the study team as much as the exercise intervention group did. Therefore, caution in interpreting comparative results is warranted.

The estimation of insulin resistance by the homeostasis model assessment (HOMA) equation resulted in lower power and high variance. Some of the data could not be included in the HOMA equation because the fasting insulin or glucose values were outside the acceptable range for the HOMA modeling. Because of the wide variability in fasting blood levels of both

glucose and insulin—depending on diurnal variation, liver function, length of time fasting, etc.—the calculated insulin resistance values showed high variability making conclusions more difficult. Future research would benefit from a standardized insulin resistance testing such as a hyperinsulinemic euglycemic clamp test.

The sample size was relatively small, given the covariance modeling analyses conducted. The models with latent executive function constructs were limited in power. This prevented us from analyzing the data with another latent cognitive variable such as inhibition. The additional model analysis with executive function as manifest variables enabled the addition of baseline physical activity as an auxiliary covariate, however, the sample size remained too small to examine all of the relationships of the manifest executive function variables with self-regulatory strategy use. Moreover, statistical power would be insufficient to replicate analyses separately by group, which may be helpful considering group was a significant covariate in the models. The fact that all participants in the study were diagnosed with metabolic disease makes comparison of the findings to healthy older adults impossible. Comparison of these models to a sample without diabetes would allow for clearer conclusions about this specific population.

Future Directions

As the REWinD Trial was a pilot exploratory trial, much future research is warranted. First of all, a true efficacy trial is needed to test whether the intervention program works. A true attentional control is necessary to test the efficacy of the REWinD intervention. Most of the physical activity interventions in older adults with T2D have used usual care or education classes as control conditions. The Diabetes Prevention Program (DPP) compared a lifestyle modification group (diet and physical activity) to oral medication and medication placebo groups. The DPP

established that lifestyle modification is viable as prevention against and treatment for T2D but by nature was not an adherence trial and therefore did not test mechanisms of adherence to lifestyle modification. Church and colleagues (2010) is one of the only studies that used a true attentional control. They compared modes of physical activity, aerobic, resistance training, and both, to a stretching control group. Again, the purpose of the research was unrelated to physical activity adherence but to appropriate exercise prescription in T2D. There is great need for a true efficacy trial, with rigorous study design, examining physical activity adherence in older adults with T2D. An extension of this research would involve testing the efficacy of the REWinD intervention compared to a true attentional control such as a stretching and education group.

Our findings indicate associations among working memory performance, cognitive flexibility and self-regulatory strategy use. However, that is not to say that executive function and self-regulation are synonymous. Executive reasoning facilitates self-regulation and self-control but the relationship of more effortful, goal-directed aspects of self-regulation, which requires cognitive flexibility, to lower order more automatic aspects of self-regulation remains unclear. Building on the REWinD pilot trial, future research warrants the inclusion of measures of more basic aspects of self-control such as autonomic function and stress physiology. It would also be beneficial to include better operationalization of self-regulatory capacity. The literature indicates a wide range in conceptualization of self-regulatory capacity. For an efficacy trial, the inclusion of a laboratory based self-regulatory depletion test may be a valuable method to measure self-regulatory capacity.

A significant gap in the literature pertains to whether physical activity is a viable mechanism to remediate cognitive impairment in older adults with T2D. Previous research has

established that certain cognitive impairments are associated with T2D (Awad et al., 2004; Ryan, 2005). Considering the existent literature regarding neuroprotective effects of physical activity and fitness in healthy older adults, a logical research question would involve examining the effects of exercise training on cognitive function in older adults with T2D. There is some evidence that regular exercise training has been shown to modify the progression of diabetic peripheral neuropathy (Balducci et al., 2006) and a couple studies have examined the association of physical activity level on cognitive status in older adults with inconclusive results (Devore, Hee Kang, Okereke, & Grodstein, 2009; Madarshahian, Hassanabadi & Nikoo, 2014). However, the effect of physical activity on brain structure or function impairments related to T2D has yet to be empirically explored.

The findings from the REWinD pilot trial support a multi-faceted approach to increasing physical activity in older adults with T2D. These results suggest that interventions combining social-cognitive based intervention with cognitive remediation focusing on updating (and maintaining) relevant information in working memory, shifting between task sets or flexibility, and inhibiting prepotent responses may increase self-regulatory strategy use or ultimately physical activity adherence. Future research is needed to test whether the combination of social cognitive behavioral intervention (such as REWinD) and cognitive training would 1) increase self-regulatory capacity, 2) increase physical activity behavior, and 3) decrease disease severity in this population.

Conclusions

Overall, the results of this study provide some support for the hypothesized self-regulatory capacity model of physical activity behavior and the efficacy of the intervention to

increase physical activity in older adults with T2D. These results indicated that specific executive functions (i.e. working memory and cognitive flexibility) are important to self-regulation and that baseline flexibility and inhibition tasks predicted physical activity six months later. These results underscore the importance of self-regulatory capacity and self-efficacy for successful physical activity adherence in older adults with T2D.

The data provide preliminary support that the REWinD intervention was effective in increasing physical activity in older adults with T2D. Individuals who participated in the intervention group, compared to an education control condition, exhibited both short- and long-term increases in self-efficacy, self-regulatory strategy use, and physical activity. There was some evidence that participation in the intervention lead to short term improvements in glycosylated hemoglobin.

Improving physical activity adherence in T2D is an important public health priority as physical activity is a powerful first-line therapy for preventing disease, alleviating symptoms, slowing disease progression and even occasionally reversing diabetes altogether. As the population continues to age, translatable interventions targeting physical activity in older adults will be crucial to controlling personal and societal impact of T2D.

CHAPTER VI: REFERENCES

Aizawa, K., Shoemaker, J. K, Overend, T. J., & Petrela, R. J. (2008). Effects of lifestyle modification on central artery stiffness in metabolic syndrome subjects with re-hypertension and/or pre-diabetes. *Diabetes Research and Clinical Practice, 83*, 249-256.

American College of Sports Medicine & American Diabetes Association Joint Position Statement. (2010). Exercise and type 2 diabetes. *Medicine & Science in Sports & Exercise, 42*(12), 2282-2303. doi: 10.1249/MSS.0b013e3181eeb61c

Angevaren, M., Aufdemkampe, G., Verhaar, H. J. J, Aleman, A., & Vanhees, L. (2008). Physical activity and enhanced fitness to improve cognitive function in older people without known cognitive impairment. *Cochrane Database of Systematic Reviews (Online: Update Software), 3*, 1-96.

Arciero, P. J., Vukovich, M. D., Holloszy, J. O., Racette, S. B. & Kohrt, W. M. (1999). Comparison of short-term diet and exercise on insulin action in individuals with abnormal glucose tolerance. *Journal of Applied Physiology, 86*, 1930-1935.

Awad, N., Gagnon, M., & Messier, C. (2004). The relationship between impaired glucose tolerance, type 2 diabetes, and cognitive function. *Journal of Clinical and Experimental Neuropsychology: Official Journal of the International Neuropsychological Society*, 26, 1044-1080.

Balducci, S., Iacobellis, G., Parisi, L., Di Biase, N., Calandriello, E., Leonetti, F., & Fallucca, F. (2006). Exercise training can modify the natural history of diabetic peripheral neuropathy. *Journal of Diabetes Complications, 20*(4), 216-223.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice Hall.

Bandura, A. (1997). *Self-Efficacy: The exercise of control.* New York: Freeman.

Bandura, A. (2004). Health promotion by social cognitive means. *Health Education and Behavior, 31,* 143-164. doi: 10.1177/1090198104263660.

Bandura, A. (2005). The primacy of self-regulation in health promotion. *Applied Psychology: An International Review, 54* (2), 245-254.

Bauer, I. M., & Baumeister, R. F. (2011). Self-regulatory strength. In Voh, K. D., Baumeister, R. F. (Eds) *Handbook of Self-Regulation* (pp. 64-82). New York, NY: Guilliford Press.

Bherer, L., Kramer A., Peterson, M., Colcombe, S., Erickson, K., & Becic E. (2005). Training effects on dual-task performance: Are there age-related differences in plasticity of attentional control? *Psychology & Aging, 20*(4), 695.

Botvinick, M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring versus selection-for-action in anterior cingulate cortex. *Nature, 402*(6758), 179-81.

Braver, T. S., & Barch, D. M. (2002). A theory of cognitive control, aging cognition and neuromodulation. *Neuroscience and Biobehavioral Review, 26*, 809-817.

Bruehl, H., Rueger, M., Dziobek, I., Sweat, V., Tirsi, A., Javier, E., Arentoft, A., Wolf, O.T., & Convit, A. (2007). Hypothalamic-pituitary-adrenal axis dysregulation and memory impairments in type 2 diabetes. *Journal of Clinical Endocrinology and Metabolism, 92,* 2439-2445.

Bruehl, H., Wolf, O. T., Sweat, V., Tirsi, A., Richardson, S., & Convit, A. (2009). Modifiers of cognitive function and brain structure in middle-aged and elderly individuals with type 2 diabetes mellitus. *Brain Research, 1280,* 186-194.

Centers for Disease Control and Prevention. (2003). National diabetes fact sheet: general information and national estimates on diabetes in the United States, 2002. Atlanta; GA: US Department of Health and Human Services, Centers for Disease Control and Prevention.

Centers for Disease Control and Prevention. (2007). U.S. Physical Activity Statistics. Accessed December 2, 2010. <http://apps.nccd.cdc.gov/PASurveillance/StateSumResultV.asp?CI=&Year=2007&State=0#data>

Centers for Disease Control and Prevention. (2008). National diabetes fact sheet: general information and national estimates on diabetes in the United States, 2007. Atlanta; GA: US Department of Health and Human Services, Centers for Disease Control and Prevention.

Chodzko-Zajko, W. J., & Moore, K. A. (1994). Physical fitness and cognitive functioning in aging. *Exercise and Sport Science Reviews, 22*, 195-220.

Convit, A. (2005). Links between cognitive impairment in insulin resistance: an explanatory model. *Neurobiology of Aging, 26S*, S133-136.

Convit, A., de Leon, M. J., Tarshish, C., De Santi, S., Twui, W., Rusinek, H., & George, A. E. (1997). Specific hippocampal volume reductions in individuals at risk for Alzheimer's disease. *Neurobiology of Aging, 18*, 131-138.

Church, T. S., Blair, S. N. Cocreham, S., Johannsen, N. Johnson, W., Kramer, K., et al., & Earnest, C. P. (2010). Effects of aerobic and resistance training on hemoglobin A1c levels in patients with type 2 diabetes: A randomized controlled trial. *Journal of the American Medical Association, 304*(20), 2253-2262.

Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R., McAuley, E., Elavsky, S., Marquez, D. X., Hu, L., & Kramer, A. F. (2006). Aerobic exercise training increases brain volume in aging humans. *Journal of Gerontology: Medical Sciences, 61A*(11), 1166-1170.

Colcombe, S. & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychological Science, 14*(2), 125-130.

Copeland, J. L. (2009). Accelerometer assessment of physical activity in active, healthy older adults. *Journal of Aging and Physical Activity, 17*, 17-30.

Cusi, K. (2009) The epidemic of type 2 diabetes mellitus: Its links to obesity, insulin resistance, and lipotoxicity. In J. G. Regensteiner, J. E. B. Reusch, K. J. Stewart, & A. Veves (Eds.), *Diabetes and Exercise* (pp 3-54). New York, New York: Humana Press.

de Jager, C. A., Budge, M. M., & Clarke, R. (2003). Utility of TICS-M for the assessment of cognitive function in older adults. *International Journal of Geriatric Psychiatry, 18*, 318-324.

den Heijer, T., Vermeer, S. E., van Dijk, E. J., Prins, N. D., Koudstaal, P.J., Hogman, A., & Breteler, M. M. B. (2003). Type 2 diabetes and atrophy of medial temporal lobe structures on brain MRI. *Diabetologia, 46*, 1604-1610.

Devore, E. E., Hee Kang, J., Okereke, O., & Grodstein, F. (2009). Physical activity levels and cognition in women with type 2 diabetes. *American Journal of Epidemiology, 170*(8), 1040-1047. doi:10.1093/aje/kwp224.

Dishman, R. K. (1982). Compliance/adherence in health-related exercise. *Health Psychology, 1,* 237-67.

Dishman, R. K., Motl, R. W., Sallis, J. F., Dunn, A L., Birnbaum, A. S., Welk, G. J. et al., & Jobe, J. B. (2005). Self-management strategies mediate self-efficacy and physical activity. *American Journal of Preventive Medicine, 29*(1), 10-18.

Duncan, G. E., Perri, M. G., Theriaque, D. W., Hutson, A. D., Eckel, R. H., & Stacpoole, P. W. (2003). Exercise training, without weight loss, increases insulin sensitivity and postherparin plasma lipase activity in previously sedentary adults. *Diabetes Care, 26*, 557-562. doi: 10.2337/diacare.26.3.557.

Dustman, R. E., Emmerson, R., & Shearer, D. (1994). Physical activity, age, and cognitive-neuropsychological function. *Journal of Aging and Physical Activity, 2*(2), 143-181.

Edelstein, S. L., Knowler, W. C., Bain, R. P., Andrew, R., Barrett-Connor, E. L., Dowse, G. K., et al. (1997). Predictors of progression from impaired glucose tolerance NIDDM: An analysis of six prospective studies. *Diabetes, 46*, 701-710.

Engleglau, M. M., Geiss, L. S., Saaddine, J. B., Boyle, J. P., Benjamin, S. M., Gregg, E. W., et al. (2004). The evolving diabetes burden in the United States. *Annals of Internal Medicine, 140*(11), 945-950.

Erickson, K. I., Colcombe, S. J., Wadhwa, R., Bherer, L., Peterson, M. S., Scalf, P. E., Kim, J. S., Alvarado, M., & Kramer, A. F. (2007). Training-induced plasticity in older adults: Effects of training on hemispheric asymmetry. *Neurobiology of Aging, 28*(2), 272- 83.

Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock L., Kim, J. S., Heo, S., Alves, H., White, S. M., Wojcicki, T. R., Mailey, E., Vieira, V. J., Martin, S. A., Pence, B. D., Woods, J. A., McAuley, E., & Kramer, A. F. (2011). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National*

Academy of Science of the United States of America, 108(7), 3017-3022. doi: 10.1073/pnas.1015950108.

Etnier, J. L., Salazar, W., Landers, D. M., Petruzzello, S. J., Han, M., & Nowell, P. (1997). The influence of physical fitness and exercise upon cognitive functioning: A meta-analysis. *Journal of Sport & Exercise Psychology, 19*, 249-277.

Etnier, J. L., Nowell, P. M., Landers, D. M., & Sibley, B. A. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research Reviews, 52*, 119-130.

Fernandez-Real, J. M. & Pickup, J. C. (2008). Innate immunity, insulin resistance and type 2 diabetes. *TRENDS in Endocrinology and Metabolism, 19*(1), 10-16. doi:10.1016/j.tem.2007.10.004

Freedson, P. S., Melanson, E., & Sirand, J. (1998). Calibration of the computer science and applications, inc. accelerometer. *Medicine & Science in Sports & Exercise, 30*, 777-781.

Gailliot, M. T., Baumeister, R. F., DeWall, C. N., Maner, J. K., Plant, E. A., Tice, D. M., Brewer, L. E., & Schmeichel, B. J. (2007). Self-control relies on glucose as a limited energy source: willpower is more than a metaphor. *Journal of Personality and Social Psychology, 92*(2), 325-336.

Gold, P. E. (1995). Role of glucose in regulating brain and cognition. *American Journal of Clinical Nutrition, 61*(4), 987S-995S.

Gold, S. M., Dziobek, I., Sweat, V., Tirsi, A., Rogers, K., Bruehl, H., Tsui, W., Richardson, S., Javier E., & Convit, A. (2007). Hippocampal damage and memory impairments as possible early brain complications of type 2 diabetes. *Diabetologia, 50*, 711-719.

Goodpaster, B. H., Katsiaras, A., & Kelley, D. E. (2003). Enhanced fat oxidation through physical activity is associated with improvements in insulin sensitivity in obesity. *Diabetes, 52*(9), 2191-2197. doi: 10.2337/diabetes.52.9.2191

Greenwood, P. M., Lambert, C., Sunderland, T., & Parasuraman, R. (2005). Effects of apolipoprotein E genotype on spatial attention, working memory, and their interaction in healthy, middle-aged adults: Results from the National Institute of Mental Health's BIOCARD study. *Neuropsychology, 19*(2), 199-211. doi: 10.1037/0894-4105.19.2.199

Grundy, S. M., Cleeman, J. I., Daniels, S. R., Donato, K. A., Eckel, R. H., Franklin, B. A., et al. (2005). Diagnosis and management of the metabolic syndrome: An American Heart Association/National Heart, Lung, and Blood Institute scientific statement. *Circulation, 112*, 2735-2752.

Gustafson, D., Lissner, L., Bengtsson, C., Bjorkelund, C., & Skoog, I. (2004). A 24-year follow-up of body mass index and cerebral atrophy. *Neurology, 63*, 1876-1881.

Gustafson, D. (2006). Adiposity indices and dementia. *The Lancet Neurology, 5*, 713 – 720.

Gunstad, J., Paul, R. H., Cohen, R. A., Tate, D. F., Spitznagel, M. B., & Gordon, E. (2007). Elevated body mass index is associated with executive dysfunction in otherwise healthy adults. *Comprehensive Psychiatry, 48*(1), 57-61.

Hall, P. A., Elias, L. J., & Crossley, M. (2006). Neurocognitive influences on health behavior in a community sample. *Health Psychology, 25*(6), 778-782. doi: 10.1037/0278-6133.25.6.778.

Hall, P. A., Fong, G. T., Epp, L. J., & Elias, L. J. (2008). Executive function moderates the intention-behavior link for physical activity and dietary behavior. *Psychology and Health, 23*(3), 309-326. doi:10.1080/14768320701212099

Hassenstab, J. J., Sweat, V., Bruehl, H. & Convit, A. (2010). Metabolic syndrome is associated with learning and recall impairment in middle age. *Dementia and Geriatric Cognitive Disorders, 29*, 356-362. doi: 10.1159/000296071.

Hofmann, W., Friese, M., Schmeichel, B. J., & Baddeley, A. D. (2011). Working memory and self-regulation. In K. D. Vohs & R. F. Baumeister, (Eds.), *Handbook of Self-Regulation* (pp. 206-225). New York: Guilford Press.

Hendrickx, H., McEwen, B. S., & van der Ouderaa, F. (2005). Metabolism, mood, and cognition in aging: The importance of lifestyle and dietary intervention. *Neurobiology of Aging, 26S*, S1-S5. doi: 10.1016/j.neurobiolaging.2005.10.005.

Hershey, T., Craft, S., Bhargava, N., & White, N. H. (1997) Memory and insulin dependent diabetes mellitus (IDDM): Effect of childhood onset and severe hypoglycemia. *Journal of the International Neuropsychological Society, 3*(6), 509-520.

Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indices in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1-55.

Hughes, S. L., Seymour, R. B., Campbell, R., Pollak, N., Huber, G., & Sharma, L., (2004). Impact of the fit and strong intervention on older adults with osteoarthritis. *Gerontologist, 44*, 217-228. doi:10.1093/geront/44.2.217.

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: Exercise effects on brain and cognition. *Nature Review. Neuroscience, 9*, 58-65.

Jagust, W., Harvey, D., Mungas, D., & Haan, M. (2005). Central obesity and the aging brain. *Archives of Neurology, 62*, 1545-1548.

Jeon, C. Y., Looken, R. P., Hu, F. B., & van Dam, R. M. (2007). Physical activity of moderate intensity and risk of type 2 diabetes: A systematic review. *Diabetes Care, 30*, 744-752.

Jongen, C., van der Grond, J., Kappelle, L. J., Biessels, G. J., Viergever, M. A., Pluim, J. P. W., & Utrecht Diabetic Encephalopathy Study Group. (2007). Automated measurement of brain and white matter lesion volume in type 2 diabetes mellitus. *Diabetologia, 50*¸ 1509- 1516. doi:10.1007/s00125-007-0688-y

Jonides, J., Schumacher, E. H., Smith, E. E., Lauber, E. J., Awh, E., Minoshima, S., & Koeppe, R. A. (1997). Verbal working memory load affects regional brain activation as measured by PET. *Journal of Cognitive Neuroscience, 9*(4), 462-475.

Kaplan, R. J., Greenwood, C. E., Winocur, G., & Wolever, T. M. (2001). Dietary protein, carbohydrate, and fat enhance memory performance in the healthy elderly. *American Journal of Clinical Nutrition, 74*(5), 687-693.

Kaplan, R. J., Greenwood, C. E., Winocur, G., & Wolever, T. M. S. (2000). Cognitive performance is associated with glucose regulation in healthy elderly persons and can be enhanced with glucose and dietary carbohydrates. *American Journal of Clinical Nutrition, 72*, 825-836.

Katula, J. A., Vitolins, M. Z., Rosenberger, E. L., Blackwell, C. S., Morgan, T. M, Lawlor, M. S., & Goff, D. C. Jr. (2011). One-year results of a community-based translation of the diabetes prevention program: Healthy-living partnerships to prevent diabetes (HELP PD) project. *Diabetes Care, 34*, 1451-1457. doi: 10.2337/dc10-2115

Kinni, H., Guo, M., Ding, J. U., Konakondla, S., Dornbos, D. III, Tran, R., Guthikonda, M., & Ding, Y. (2011). Cerebral metabolism after forced or voluntary physical exercise. *Brain Research, 1388*, 48-55. doi: 10.1016/j.brainres.2011.02.076.

Korf, E. S. C., Scheltens, P., White, L. R., & Launer L. J. (2006). Brain aging in very old men with type 2 diabetes: The Honolulu-Asia aging study. *Diabetes Care, 29*, 2268-2274.

Kramer, A. F., & Erickson, K. I. (2007). Capitalizing on cortical plasticity: influence of physical activity on cognition and brain function. *Trends in Cognitive Science, 8*, 342-348.

Kramer, A. F., Hahn, S., Cohen, N. J., Banich, M. T., McAuley, E., Harrison, C. R., Chason, J., Vakil, E., Bardell, L., Boileau, R. A., & Colcombe, A. (1999). Ageing, fitness and neurocognitive function. *Nature, 400*(6743), 418-419. doi: 10.1038/22682

Kruglanski, A. W., Shah, J. Y., Fishbach, A., Friedman, R., Chun, W. Y., & Sleeth-Keppler, D. (2002). A theory of goal systems. In M. P. Zanna (Ed.), *Advances in experimental social Psychology* (Vol. 34, pp. 331-378). San Diego, CA: Academic Press.

Kumar, A., Haroon, E., Darwin, C., Pham, D., Ajilore, O., Rodriguez, G. & Mintz, J. (2008). Gray matter prefrontal changes in type 2 diabetes detected using MRI. *Journal of Magnetic Resonance Imaging, 27,* 14-19. doi:10.1002/jmri.21224

LaMonte, M. J., Blair, S. N., & Church, T. S. (2005). Physical activity and diabetes prevention. *Journal of Applied Physiology, 99*(3), 1205-1213.

Leibson, C. L., Rocca, W. A., Hanson, V. A., Cha, R., Kokmen, E., O'Brien, P. C., & Palumbo, P. J. (1997). Risk of dementia among persons with diabetes mellitus: a population-based cohort study. *American Journal of Epidemiology, 145*, 301-308.

The Look AHEAD Research Group. (2010). Long-term effects of a lifestyle intervention on weight and cardiovascular risk factors in individuals with type 2 diabetes mellitus: Four-year results of the Look AHEAD trial. *Archives of Internal Medicine, 170*(17), 1566-1575.

Luciano, E., Carneiro, E. M., Carvalho, C. R., Carvalheira, J. B., Peres, S. B. Reis, M. A., Saad, M. J. A., Boschero A. C., & Velloso, L. A. (2002). Endurance training improves responsiveness to insulin and modulates insulin signaling transduction through the phosphatidylinositol 3-kinase/Akt-1 pathway. *European Journal of Endocrinology, 147*, 149-157. doi: 10.1530/eje.0.1470149.

MacKinnon, D. P., Krull, J. L., & Lockwood, C. M. (2000). Equivalence of mediation, confounding, and suppression effect. *Prevention Science, 1*(4), 173- 181.

Madarshahian, F., Hassanabadi, M., & Nikoo, M. K. (2014). Cognitive status and foot self-care practice in overweight diabetics, engaged in different levels of physical activity. *Journal of Diabetes & Metabolic Disorders, 13*(31).

Maes, S., & Karoly, P. (2005). Self-regulation assessment and intervention in physical health and illness: A review. *Applied Psychology: An International Review, 54*(2), 267-299.

Mailey, E. L., Gothe, N. P., Wojcicki, T. R., Szabo, A. N., Olson, E. A., Mullen, S. P., Fanning, J. T., Motl, R. W., & McAuley, E. (2014). Influence of allowable interruption period on estimates of accelerometer wear time and sedentary time in older adults. *Journal of Aging and Physical Activity, 22*(2), 255-260. doi: 10.1123/japa.2013-0021.

Masse, L., Fummeler, B., Anderson, C., Mathews, C., Trost, S., Catellier, D., & Treuth, M. (2005). Accelerometer data reduction: A comparison of four reduction algorithms on select outcome variables. *Medicine and Science in Sports and Exercise, 37*(11), S544-S554.

Matos. A., Ropelle, E. R., Pauli, J. R., Frederico, M. J. S., de Pinho, R. A., Velloso, L. A., & De Souza, C. T. (2010). Acute exercise reverses TRB3 expression in the skeletal muscle and

ameliorates whole body insulin sensitivity in diabetic mice. *Acta Physiologica, 198*, 61-69. doi: 10.1111/j.1748-1716.2009.02031.x

McAuley, E. (1992). The role of efficacy cognitions in the prediction of exercise behavior in middle-aged adults. *Journal of Behavioral Medicine,15*(1), 65-88.

McAuley, E. & Blissmer, B. (2000). Self-efficacy determinants and consequences of physical activity. *Exercise and Sport Sciences Reviews, 28*(2), 85-88.

McAuley, E. Blissmer, B., Marquez, D. X., Jerome, G. J., Kramer, A. F., & Katula, J. (2000). Social relations, physical activity, and well-being in older adults. *Preventive Medicine 31*(5), 608-617.

McAuley, E., Hall, K. S., Motl, R. W., White, S. M., Wojcicki, T. R., Hu, L., & Doerksen, S. E. (2009). Trajectory of declines in physical activity in community-dwelling older women: Social cognitive influences. *Journal of Gerontology: Psychological Sciences, 64B*(5), 543-550. doi:10.1093/geronb/gbp049

McAuley, E., Jerome, G. J., Marquez, D. X., Elavsky, S., & Blissmer, B. (2003). Exercise self-efficacy in older adults: Social, affective and behavioral influences. *Annals of Behavioral Medicine, 25*, 1-7. doi:10.1207/S15324796ABM2501_01

McAuley, E. Mailey, E. L., Mullen, S. P., Szabo, A. N., Wojckicki, T. R., White, S. M., Gothe, N., Olson, E. A., & Kramer, A. F. (2011). Growth trajectories of exercise self-efficacy in older adults: influence of measures and initial status. *Health Psychology, 30*(1), 75-83. doi: 10.1037/a0021567.

McAuley, E., & Mihalko, S. L. (1998). Measuring exercise-related self-efficacy. In J. L. Duda (Ed.), *Advances in sport and exercise psychology measurement* (pp. 371-390). Morgantown, WV: Fitness Information Technology.

McAuley, E., Mullen, S. P., Szabo, A. N., White, S. M., Wojcicki, T. R., Mailey, E. L., Gothe, N., Olson, E. A., Voss, M., Erickson, K., Prakash, R., & Kramer, A. (2011). Self-regulatory processes and exercise adherence in older adults: Executive function and self-efficacy effects. *American Journal of Preventive Medicine, 41*(3), 284-290. doi: 10.1016/j.amepre.2011.04.014

Messier C. (2005). Impact of impaired glucose tolerance and Type 2 diabetes on cognitive aging. *Neurobiology of Aging, 26S,* S94-97.

Milham, M. P., Erickson, K. I., Banich, M. T., Kramer, A. F., Webb, A., Wszalek, T., & Cohen, N. J. (2002). Attentional control in the aging brain: insights from an fMRI study of the stroop task. *Brain and Cognition, 49*(3), 277-296.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 2668-2682.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100.

Moore, S. M., Charvat, J. M., Gordon, N. H., Pashkow, F., Ribisl, P., Roberts, B. L., & Rocco, M. (2006). Effects of a CHANGE intervention to increase exercise maintenance following cardiac events. *Annals of Behavioral Medicine, 31*, 53-62. doi:10.1207/s15324796abm3101_9.

Morrato, E. H., Hill, J. O., Wyatt, H. R., Ghushchyan, V., & Sullivan, P. W. (2007). Physical activity in the U.S. adults with diabetes and at risk for developing diabetes, 2003. *Diabetes Care, 30*(2), 203-209.

Musen, G., Jacobson, A. M., Bolo, N. R., Simonson, D. C., Shenton, M. E., McCartney, R. L., Flores, V. L., & Hoogenboom, W. S. (2012). Resting-state brain functional connectivity is altered in type 2 diabetes. *Diabetes, 61,* 2375-2379.

Múthen, L. K., & Múthen, B. O. (2010). *Mplus User's Guide: Sixth Edition.* Múthen & Múthen, Los Angeles, CA.

Nwasuruba, C. K., Khan, M., & Egede, L. E. (2007). Racial/ethnic differences in multiples self-care behaviors in adults with diabetes. *Journal of General Internal Medicine, 22*, 115-120.

Pannacciulli, N., Del Parigi, A., Chen, K., Le, D. S. N. T., Reiman, E. M., & Tataranni, P. A. (2006). Brain abnormalities in human obesity: A voxel-based morphometric study. *Neuroimage, 31,* 1419-1425.

Pour, O. R. & Dagogo-Jack, S. (2011). Prediabetes as a therapeutic target. *Clinical Chemistry, 57*(2). doi: 10.1373/clinchem.2010.149096

Reitan, R. M. (1958). Validity of the trail making test as an indication of organic brain damage. *Perceptual and Motor Skills, 8*¸ 271-276.

Reitan, R. M. (1992). *Trail making test: manual for administration and scoring*. Tuscon, AZ: Retain Neuropsychology Laboratory.

Reynolds, C. R. (2002). Comprehensive trail making test (CTMT). *Austin,* TX: Pro-Ed.

Ryan, C. M. (2005). Diabetes, aging, and cognitive decline. *Neurobiology of Aging,26S*, S21-25.

Salthouse, T. A., Toth, J., Daniels, K., Parks, C., Pak, R., Wolbrette, M., & Hocking, K. J. (2000). Effects of aging on efficiency of task switching in a variant of the trail making test. *Neuropsychology, 14*(1), 102-111. doi:10.1037//0894-4105.14.1.102

Seifert, T., Rasmussen P., Brassard, P., Homann, P. H., Wissenberg, M., Nordby P., Stallknecht, B., Secher, N. H., & Nielsen, H. B. (2009). Cerebral oxygenation and metabolism during exercise following three months of endurance training in healthy overweight males. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology, 297*, R867-R876.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information-processing. 1. Detection, search and attention. *Psychological Review, 84*(1), 1-66. doi:10.1037/0033-295X.84.1.1

Selim, M., Jones, R., Novak, P., Zhao, P., & Novak, V. (2008). The effects of body mass index on cerebral blood flow velocity. *Clinical Autonomic Research, 18,* 331-338.

Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: A meta-analysis. *Pediatric Exercise Science, 15*(3), 243-256.

Skalicky, J., Muzakova, V., Kandar, R., Meloun, M., Rousar, T., & Palicka, V. (2008). Evaluation of oxidative stress and inflammation in obese adults with metabolic syndrome. *Clinical Chemistry and Laboratory Medicine, 46,* 499. doi: 10.1515/CCLM.2008.096

Smith, P. J., Blumenthal, J. A., Hoffman, B. M., Cooper, H., Strauman, T. A., Welsh-Bohmer, K., Browndyke, J. N., & Sherwood, A. (2010). Aerobic exercise and neurocognitive performance: A meta-analytic review of randomized controlled trials. *Psychosomatic Medicine, 72,* 239-252. doi: 10.1097/PSY.0b013e3181d14633

Spirduso, W. W., & Clifford, P. (1978). Replication of age and physical activity effects on reaction and movement time. *Journal of Gerontology, 33*(1), 26-30.

Stuss, D. T., & Alexander, M. P. (2000). Executive functions and the frontal lobes: A conceptual view. *Psychological Research, 63,* 289-298.

Stranahan, A. M., Arumugam, T. V., Cutler, R. G., Lee, K., Egan, J. M., & Mattson, M. P. (2008). Diabetes impairs hippocampal function through glucocorticoid-mediated effects on new and mature neurons. *Nature Neuroscience, 11*(3), 309-317. doi:10.1038/nn2055

Siu, X., LaMonte, M. J., Laditka, J. N., Hardin, J. W., Chase, N., Hooker, S. P., & Blair, S. N. (2007). Cardiorespiratory fitness and adiposity as mortality predictors in older adults. *Journal of the American Medical Association, 298,* 2507-2516.

Sweat, V., Starr, V., Bruehl, H., Arentoft, A., Tirsi, A., Javier, E., & Convit, A. (2008). C-reactive protein is linked to lower cognitive performance in overweight and obese women. *Inflammation, 31*(3), 198-207. doi:10.1007/s10753-008-9065-3

Taki, Y., Kinomura, S., Sato, K., Inoue, K., Goto, R., Okada, K., Uchida, S., Kawashima, R., & Fukuda, H. (2008). Relationship between body mass index and gray matter volume in 1,428 healthy individuals. *Obesity, 16,* 119-124. doi:10.1038/oby.2007.4

Taylor, L. M., Spence, J. C., Raine, K., Plotnikoff, R. C., Vallance, J. K., & Sharma, A. M. (2010). Physical activity and health-related quality of life in individuals with prediabetes. *Diabetes Research and Clinical Practice, 90,* 15 – 21. doi:10.1016/j.diabres.2010.04.011

Touati, S., Meziri, F., Devaux, S., Berthelot, A., Touyz, R., & Laurent, P. (2011). Exercise reverses metabolic syndrome in high-fat diet-induced obese rats. *Medicine & Science in Sports & Exercise, 43*(3), 398-407. doi:10.1249/MSS.0b013e3181eeb12d

Umpierre, D., Ribeiro, P. A., Kramer, C. K., Leitão, C. B., Zucatti, A. T. N., Asevedo, M. J., Gross, J. L., Ribeiro, J. P., & Schaan, B. D. (2011). Physical activity advice only or

structured exercise training and association with HbA1c levels in type 2 diabetes. *Journal of the American Medical Association, 305*(17), 1790- 1799.

Umstattd, M. R., Motl, R., Wilcox, S., Saunders, R., & Watford, M. (2009). Measuring physical activity self-regulation strategies in older adults. *Journal of Physical Activity and Health,6*, S105-S112.

van Harten, B., Oosterman, J. M., Potter van Loon, B.-J., Scheltens, P., & Weinstein, H. C. (2007). Brain lesions on MRI in elderly patients with type 2 diabetes mellitus. *European Neurology, 57*, 70-74. doi:10.1159/000098054.

Voss, M. W., Prakash, R. S., Erickson, K. I., Basak, C., Chaddock, L., Kim, J. S., Alves, H., Heo, S., Szabo, A. N., White, S. M., Wojcicki, T. R., Mailey, E. L., Gothe, N., Olson, E. A., McAuley, E., & Kramer, A. F. (2010). Plasticity of brain networks in a randomized intervention trial of exercise training in older adults. *Frontiers in Aging Neuroscience*, *2*, 32. doi:10.3389/fnagi.2010.00032

Wagner, D. D., & Heatherton, T. F. (2010). Giving in to temptation: The emerging cognitive neuroscience of self-regulatory failure. In: Vohs, K. D., Baumeister, R. F., (Eds.) Handbook of self-regulation: research, theory, and applications. New York, NY: Guilford Press

Weaver, J. D., Huang, M. H., Albert, M., Harris, T., Rowe, J. W., & Seeman, T. E. (2002). Interleukin-6 and risk of cognitive decline-MacArthur studies of successful aging. *Neurology, 59*(3), 371-378.

Weinstein, A. M., Voss, M. W., Prakash, R. S., Chaddock, L., Szabo, A., White, S. M., Wojcicki, T. R., Mailey, E., McAuley, E., Kramer, A. F., & Erickson, K. I. (2011). The

association between aerobic fitness and executive function is mediated by prefrontal cortex volume. *Brain, Behavior, and Immunity.* doi: 10.1016/j.bbi.2011.11.008

Whitmer, R. A., Gustafson, D. R., Barrett-Connor, E., Haan, M. N., Gunderson, E. P., & Yaffe, K. (2008). Central obesity and increased risk of dementia more than three decades later. *Neurology, 71*(4), 1057-1064.

Yaspelkis, B. B., Lessar, S. J., Reeder, D. W., Limon, J. J., Saito, M., Rivas, D. A., Kvasha, I., & Hawley, J. A. (2007). Exercise reverses high-fat diet-induced impairments on compartmentalization and activation of components of the insulin-signaling cascade in skeletal muscle. *American Journal of Physiology, Endocrinology & Metabolism, 293*, E941-E949. doi: 10.1152/ajpendo.00230.2007

CHAPTER VII: TABLES

Table 1. Baseline Descriptive Values for the REWinD Trial

	Intervention (n = 58)	Usual Care (n = 58)	Total (n = 116)
Age, y	61.3 ± 5.8	62.4 ± 6.9	61.8 ± 6.4
Sex, No. (%)			
Female	37 (63.8)	38 (65.5)	75 (64.7)
Male	21 (36.2)	20 (34.5)	41 (35.3)
Race, No. (%)			
African American	9 (15.5)	7 (12.1)	16 (13.8)
Asian	2 (3.4)	1 (1.7)	3 (2.6)
White	45 (77.6)	49 (84.5)	94 (81.0)
Multi-Racial	2 (3.4)	1 (1.7)	3 (2.6)
Ethnicity, No. (%)			
Hispanic or Latino	2 (3.4)	None	2 (1.7)
Not Hispanic or Latino	56 (96.6)	58 (100)	114 (98.3)
Education[a], No. (%)			
Not High School Graduate	1 (1.8)	2 (3.4)	3 (2.6)
High School Diploma	7 (12.3)	10 (17.2)	17 (14.8)
Some College	17 (29.8)	15 (25.9)	32 (27.8)
College Graduate	15 (26.3)	21 (36.2)	36 (31.3)
Graduate Degree	17 (29.8)	10 (17.3)	27 (23.5)
Employment[a], No. (%)			
Working Full Time	19 (33.3)	21 (36.2)	40 (34.8)
Working Part Time	14 (24.6)	14 (24.1)	28 (24.3)
Retired	20 (35.1)	17 (29.3)	37 (32.2)
Unemployed/Disability	3 (5.3)	6 (10.3)	10 (8.7)
Annual Income[a], No. (%)			
< $20,000	6 (10.8)	9 (16.4)	15 (13.5)
≤ $40,000	12 (21.5)	11 (20.0)	23 (20.7)
> $40,000	38 (67.9)	35 (63.6)	73 (65.8)
Taking oral medication, No. (%)	41 (70.7)	37 (63.8)	78 (67.2)
Taking insulin, No. (%)	16 (27.6)	10 (17.2)	26 (22.4)
Body Mass Index	34.8 ± 5.5	36.8 ± 7.1	35.8 ± 6.4
H_bA1_c (%)	7.30 ± 1.5	6.90 ± 1.3	7.11 ± 1.4

[a] Frequencies may not sum to group totals due to unreported data

Table 2. Intervention Exercise Log Weekly Means and Standard Deviations

Week	Missing No(%)	Mean (mins)	± SD
Week 1	4 (7.8)	92.4	62.8
Week 2	5 (9.8)	115.7	57.1
Week 3	4 (7.8)	162.4	84.2
Week 4	6 (11.7)	157.7	75.2
Week 5	5 (9.8)	195.4	120.6
Week 6	9 (17.6)	180.8	66.9
Week 7	12 (23.5)	181.4	84.3
Week 8	16 (31.3)	222.0	101.1
Average	--	158.06	62.22

Table 3. Education Group Website Engagement Overview

Module	Comments	Views
Week 1	36	377
Week 2	31	310
Week 3	27	272
Week 4	27	272
Week 5	26	195
Week 6	19	147
Week 7	19	146
Week 8	16	112

Table 4. Short- and long-term intervention effect on self-regulatory strategy use

		M0	M2	Cohen's *d*	*p*	M6	Cohen's *d*	*p*
		M(SD)	M(SD)			M(SD)		
Self-regulatory Strategy Use	Exercise	24.4(8.1)	40.1(10.2)	1.70	<.001	33.6(11.3)	.94	<.001
	Education	25.7(8.6)	27.0(9.8)	.14	n.s.	27.5(9.4)	.20	.09

Table 5. Short- and long-term intervention effects on self-efficacy (compared to baseline)

		M0	W2	Cohen's *d*	*p*	M2	Cohen's *d*	*p*	M6	Cohen's *d*	*p*
		M(SD)	M(SD)			M(SD)			M(SD)		
SEW	Exercise	54.8(30.0)	74.0(26.0)	.68	<.001	80.6(23.1)	.94	<.001	75.3(24.9)	.74	<.001
	Education	41.6(28.9)	46.4(28.9)	.16	n.s.	45.9(32.7)	.14	n.s.	42.1(33.3)	.02	n.s.
LSE	Exercise	40.4(17.6)	42.4(22.1)	.10	n.s.	43.8(16.2)	.20	n.s.	37.1(18.0)	-.18	n.s.
	Education	33.6(18.7)	31.7(19.8)	-.09	n.s.	27.8(20.4)	-.30	<.01	25.6(22.4)	-.39	<.01
BARSE	Exercise	52.7(24.2)	62.9(24.3)	.42	<.001	57.8(26.7)	.20	n.s.	48.8(29.1)	-.15	n.s.
	Education	45.1(25.7)	48.4(26.1)	.13	n.s.	39.7(26.7)	-.21	n.s.	29.6(23.7)	-.63	<.001
EXSE	Exercise	58.3(30.1)	66.2(29.9)	.26	<.001	67.8(30.0)	.32	<.01	57.2(32.1)	-.04	n.s.
	Education	41.0(31.9)	48.1(31.4)	.22	.06	39.2(34.2)	-.05	n.s.	38.2(37.0)	-.08	n.s.

Table 6. Short- and long-term intervention effect on glycosylated hemoglobin

		M0 M(SD)	M2 M(SD)	Cohen's *d*	*p*	M6 M(SD)	Cohen's *d*	*p*
Glycosylated Hemoglobin	Exercise	7.2(1.3)	6.9(0.9)	-.27	<.01	7.2(1.5)	.00	n.s.
	Education	6.7(1.1)	6.8(1.1)	.09	n.s.	6.5(0.7)	-.22	.14

Table 7. Correlations between change in minutes of moderate-to-vigorous physical activity (from m0 to m2) and self-efficacy, and self-regulatory strategy use.

Measure	Time-Point	Correlation w/ Δ MVPA	*p*
Lifestyle self-efficacy	M2	.329	<.01
	M6	.359	<.01
Self-efficacy for walking	M2	.319	<.01
	M6	.387	<.01
Exercise self-efficacy (duration)	M2	.491	<.01
	M6	.389	<.01
Barriers self-efficacy	M2	.376	<.01
	M6	.381	<.01
Self-regulatory strategy use	M2	.391	<.01
	M6	.315	<.01

Note: Correlations controlled for age, gender, and income.

Table 8.a. Regression analysis of effect of change in physical activity (from m0 to m2) on self-efficacy at month two

Predictors	Lifestyle Self-Efficacy					Walking Self-Efficacy					Exercise Self-Efficacy					Barriers Self-Efficacy				
	β	*t*	*p*	R^2	*p*	*β*	*t*	*p*	R^2	*p*	*β*	*t*	*p*	R^2	*p*	*β*	*t*	*p*	R^2	*p*
age	-.08	-.87	n.s.			.02	.25	n.s.			-.06	-.71	n.s.			-.14	-1.7	n.s.		
gender	.06	.72	n.s.			.16	2.0	<.05			.22	2.8	<.05			.31	3.8	<.01		
income	.04	.47	n.s.	.42	<.01	.08	1.0	n.s.	.44	<.01	.02	.23	n.s.	.32	<.01	-.09	-1.1	n.s.	.39	<.01
Baseline value	.61	6.9	<.01			.56	6.7	<.01			.43	4.9	<.01			.53	6.3	<.01		
Δ minutes MVPA	.16	1.9	<.05	.02	<.01	.17	2.1	<.05	.03	<.05	.35	4.1	<.01	.11	<.01	.28	3.4	<.01	.07	<.01

Table 8.b. Regression analysis of effect of change in physical activity (from m0 to m2) on self-efficacy at month six

Predictors	Lifestyle Self-Efficacy					Walking Self-Efficacy					Exercise Self-Efficacy					Barriers Self-Efficacy				
	β	*t*	*p*	R^2	*p*	*β*	*t*	*p*	R^2	*p*	*β*	*t*	*p*	R^2	*p*	*β*	*t*	*p*	R^2	*p*
age	.00	-.01	n.s.			.03	.40	n.s.			.08	.83	n.s.			-.02	-.27	n.s.		
gender	.14	1.5	n.s.			.13	1.5	n.s.			.14	1.4	n.s.			.14	1.6	n.s.		
income	.04	.47	n.s.	.28	<.01	-.09	-1.0	n.s.	.40	<.01	.03	.28	n.s.	.17	<.01	-.07	-.86	n.s.	.37	<.01
Baseline value	.45	4.5	<.01			.58	6.6	<.01			.27	2.7	<.01			.56	6.5	<.01		
Δ minutes MVPA	.24	2.4	<.05	.05	<.01	.28	3.3	<.01	.07	<.01	.32	3.2	<.01	.09	<.01	.28	3.3	<.01	.07	<.01

Table 9.a. Regression analysis of effect of change in physical activity (from m0 to m2) on self-regulatory strategy use at month two

	Self-Regulatory Strategy Use				
Predictors	*β*	*t*	*p*	R^2	*p*
age	.01	.16	n.s.	.22	<.01
gender	.11	.1.3	n.s.		
income	.17	1.9	.06		
Baseline value	.34	3.9	<.01		
Δ minutes MVPA/day	.38	4.3	<.01	.13	<.01

Table 9.b. Regression analysis of effect of change in physical activity (from m0 to m2) on self-regulatory strategy use at month six

	Self-Regulatory Strategy Use				
Predictors	*β*	*t*	*p*	R^2	*p*
age	.09	.95	n.s.	.26	<.01
gender	-.04	-.46	n.s.		
income	-.05	-.51	n.s.		
Baseline value	.46	4.9	<.001		
Δ minutes MVPA/day	.26	2.8	<.01	.06	<.01

Table 10. Short- and long-term intervention effects on physical activity measured by accelerometry (compared to baseline)

		M0	M2	Cohen's *d*	*p*	M6	Cohen's *d*	*p*
		M(SD)	M(SD)			M(SD)		
Minutes of MVPA/day	Exercise	8.9(9.7)	20.2(18.1)	.82	<.01	11.8(11.4)	.27	<.01
	Education	6.8(7.9)	7.6(9.5)	.09	n.s.	6.8(8.2)	.00	n.s.

CHAPTER VIII: FIGURES

Figure 1.Self-Regulatory Processes Indirect Influence on Physical Activity Behavior through Self-Efficacy

Figure 2. The Triadic Reciprocity of the Social Cognitive Theory.

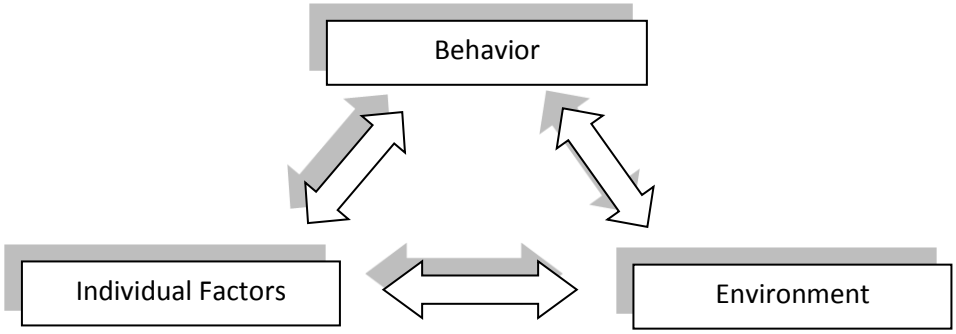


Figure 3. Illustration of Exercise Intervention Components

Week	Walk 1	Walk 2	Walk 3	Walk 4	Walk 5	Group
1	On-site (10-20mins)	On-site (15-25mins)	On-site (15-25mins)	--	--	Group 1
2	On-site (15-25mins)	On-site (15-25mins)	On-site (15-25mins)	--	--	--
3	On-site (20-30mins)	On-site (20-30mins)	At home (20-30mins)	At home (20-30mins)	--	Group 2
4	On-site (20-30mins)	On-site (20-30mins)	At home (20-30mins)	At home (20-30mins)	--	--
5	On-site (30+mins)	At home (30+mins)	At home (30+mins)	At home (30+mins)	At home (30+mins)	Group 3
6	On-site (30+mins)	At home (30+mins)	At home (30+mins)	At home (30+mins)	At home (30+mins)	--
7	At home (30+mins)	At home (30+mins)	At home (30+mins)	At home (30+mins)	At home (30+mins)	--
8	At home (30+mins)	At home (30+mins)	At home (30+mins)	At home (30+mins)	At home (30+mins)	Group 4

Workshop Number	Topics/Activities
Group Workshop 1	**Introduction** **PA Guidelines & Safety** **Goal-Setting**
Group Workshop 2	**Goal-setting/Monitoring** **Barriers and Strategies** **Planning/scheduling**
Group Workshop 3	**Goal-Setting/Monitoring** **Confidence Building** **Cognitive Reframing**
Group Workshop 4	**Goal-Setting/Monitoring** **Relapse Prevention & Recovery**

Figure 4. The REWinD Trial CONSORT

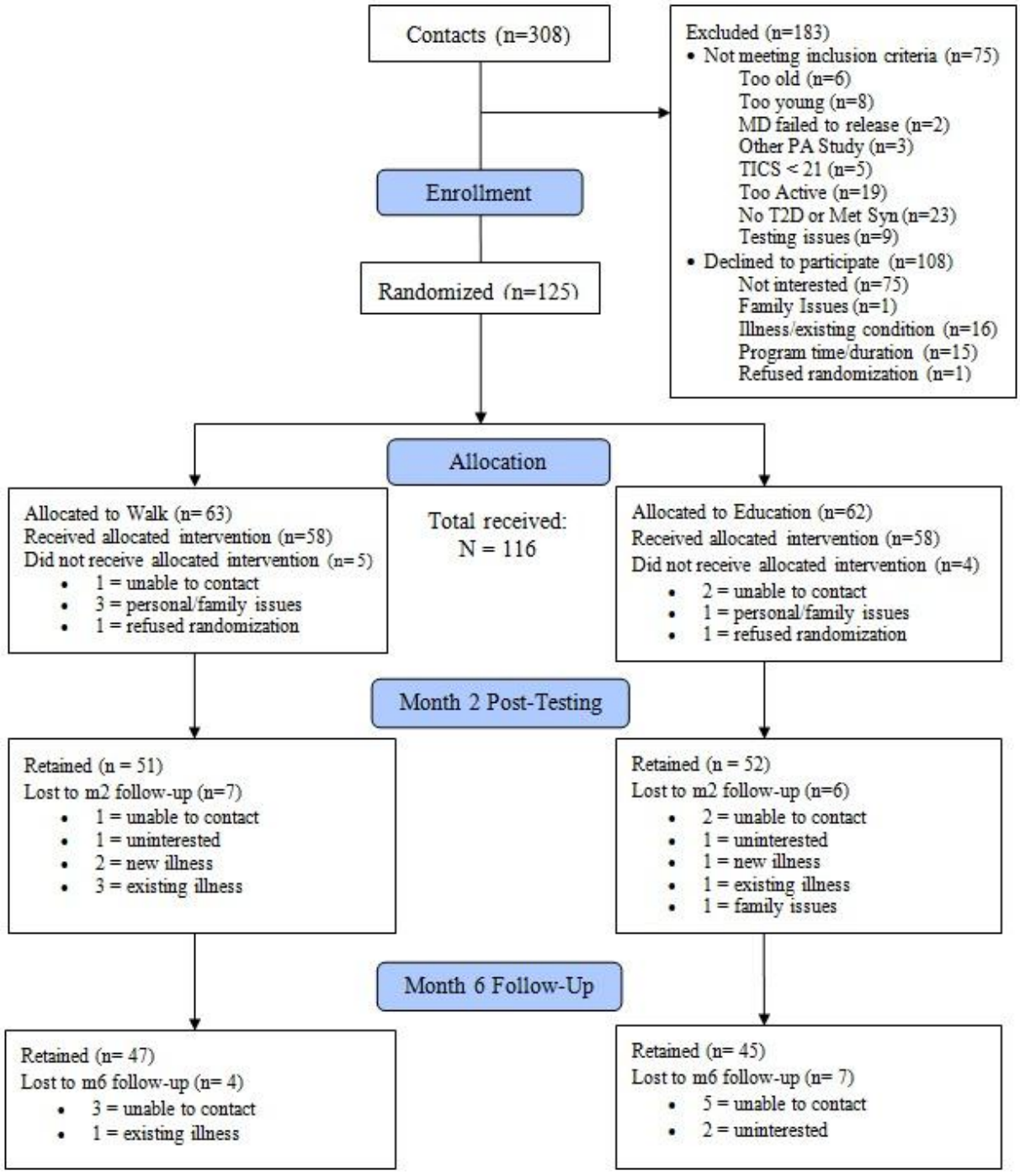


Figure 5. Objective 1—Model 1

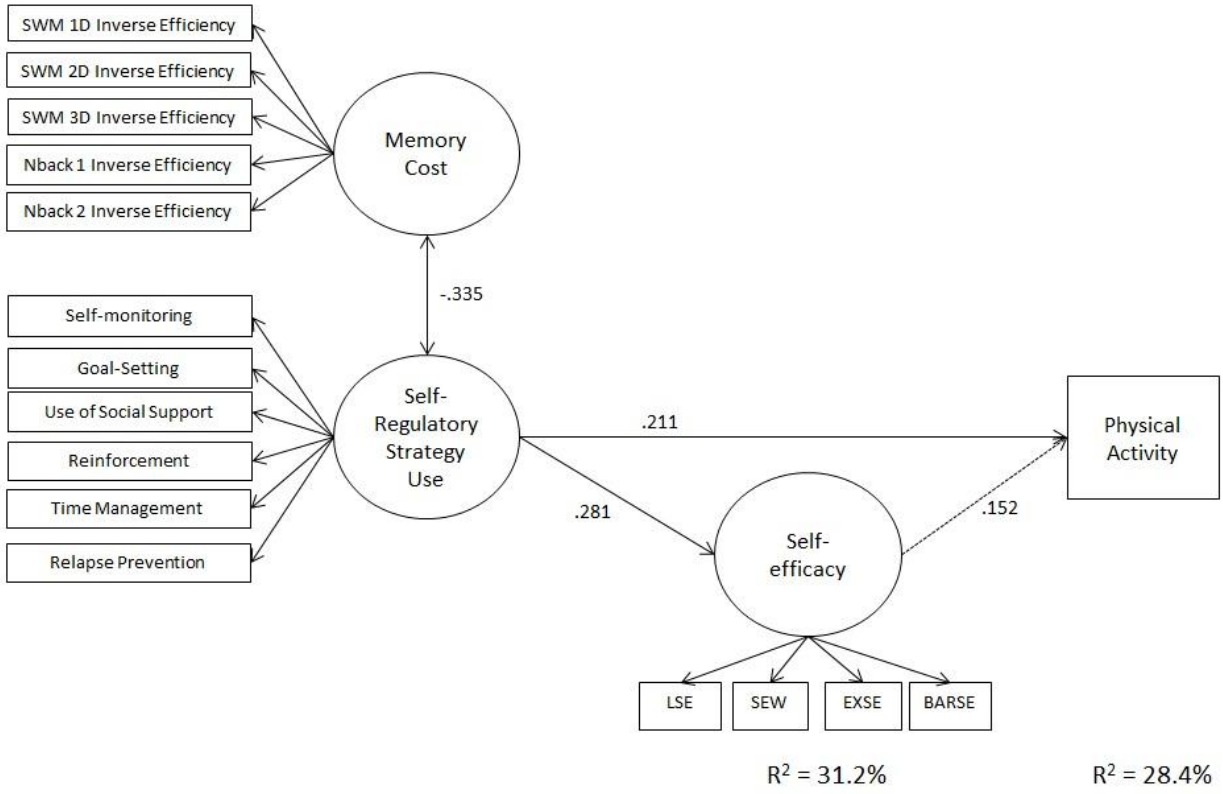


Figure 6. Objective 1—Model 2

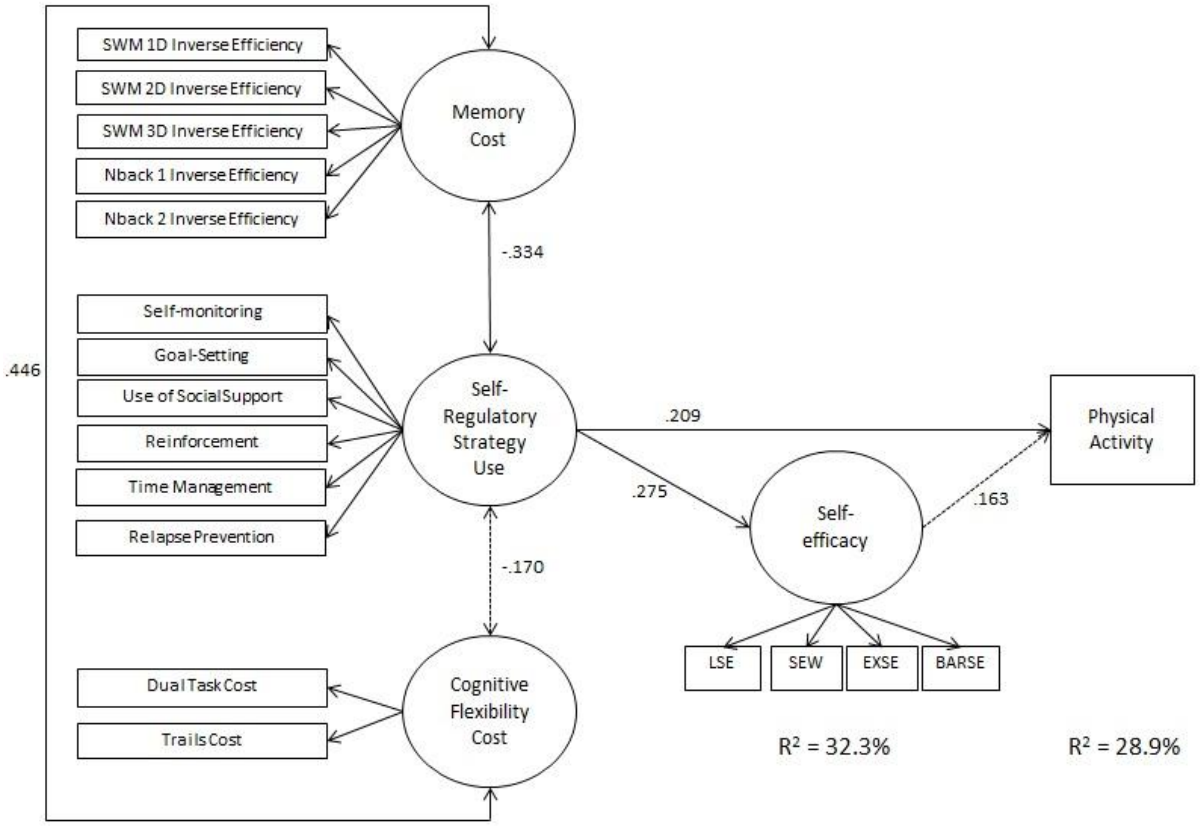


Figure 7. Objective 1—Model 3

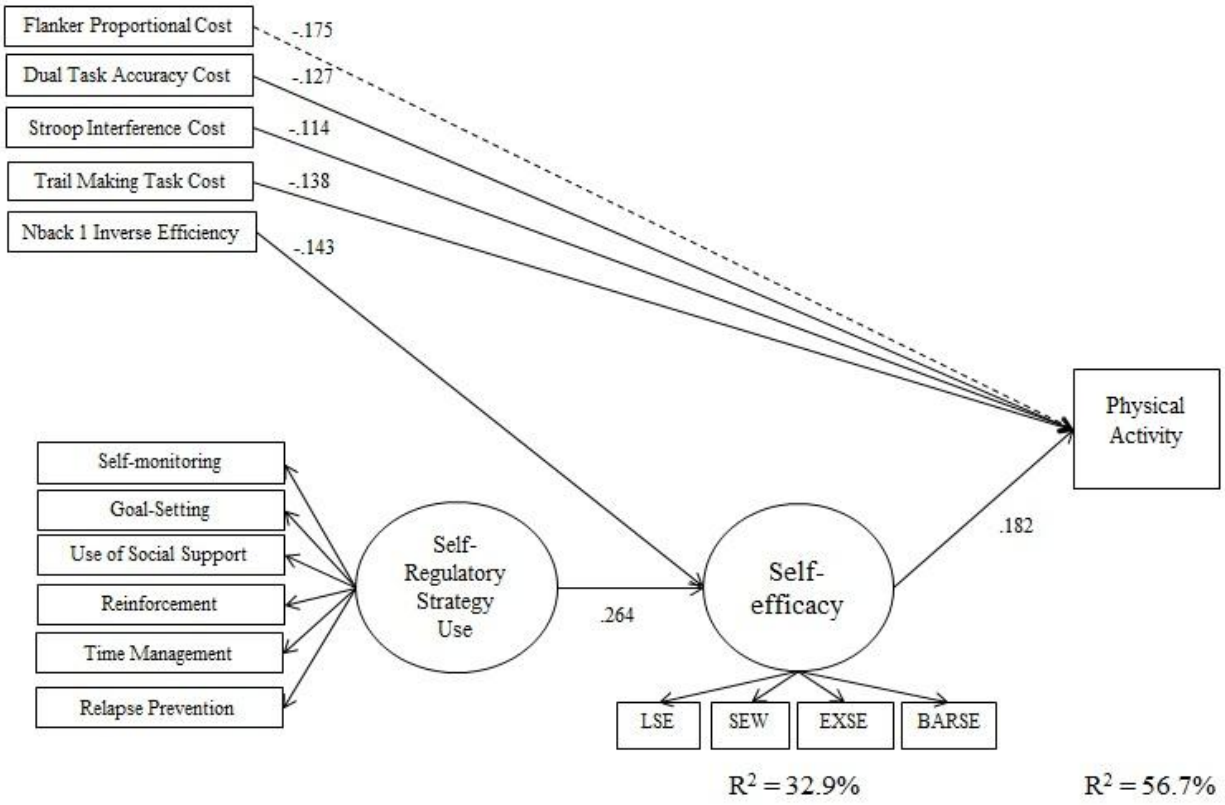


Figure 8. Trajectories of self-regulatory strategy use by group

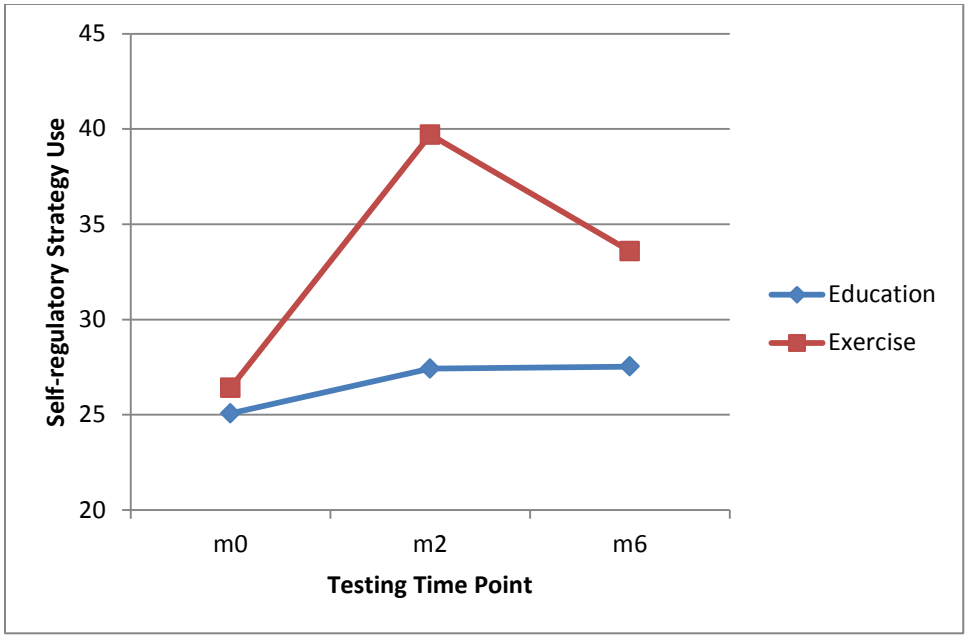
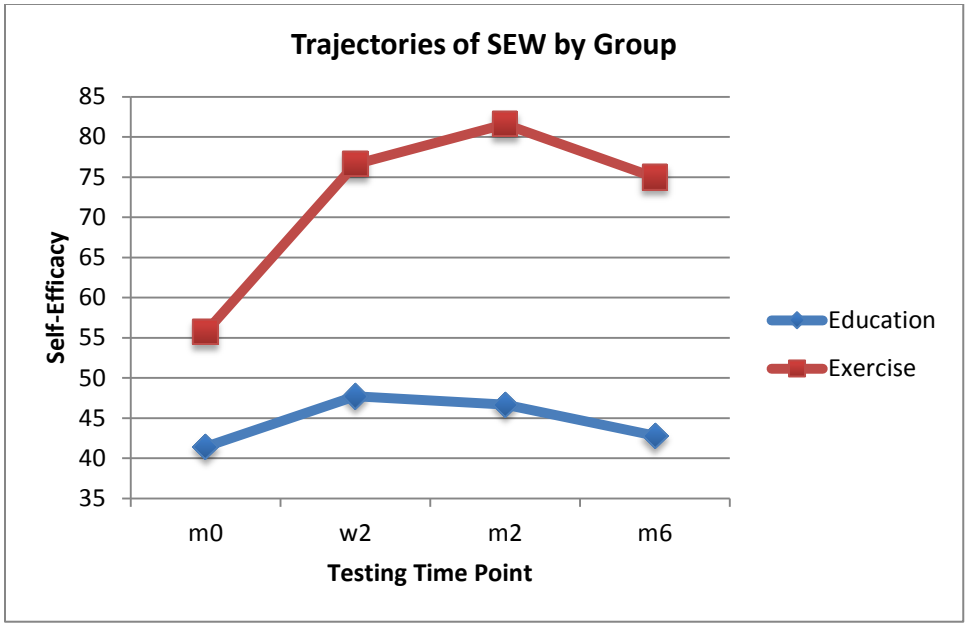


Figure 9. Trajectories of Self-Efficacy by Group



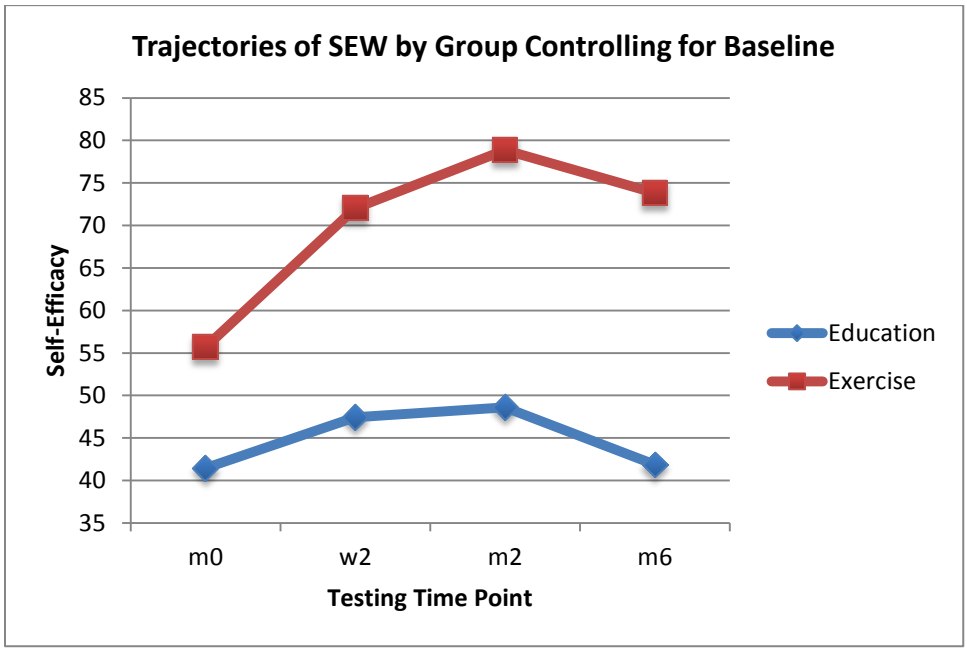
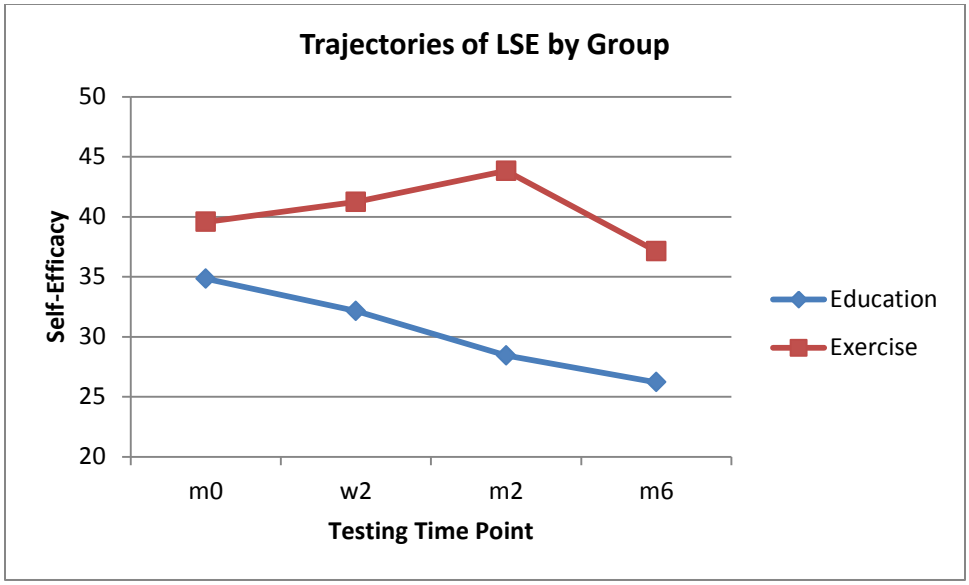


Figure 9. Trajectories of Self-Efficacy by Group (cont.)



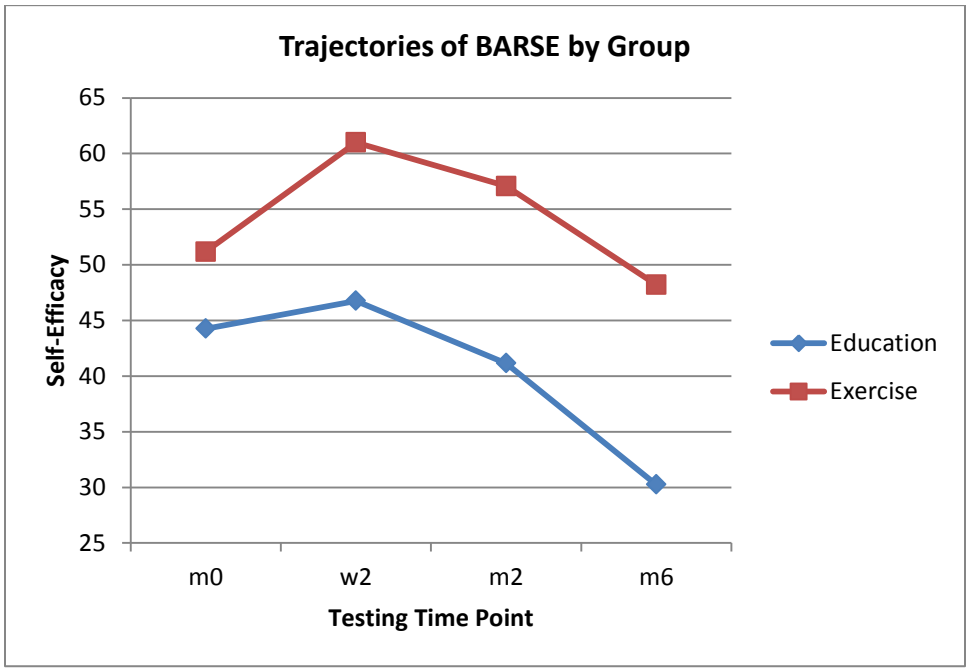
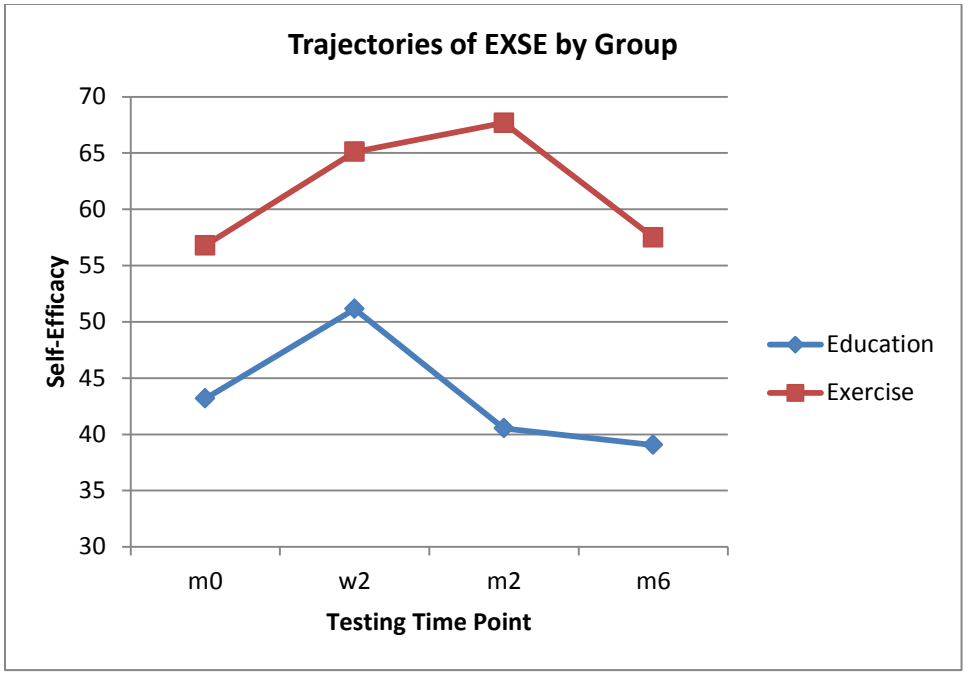


Figure 9. Trajectories of Self-Efficacy by Group (cont.)



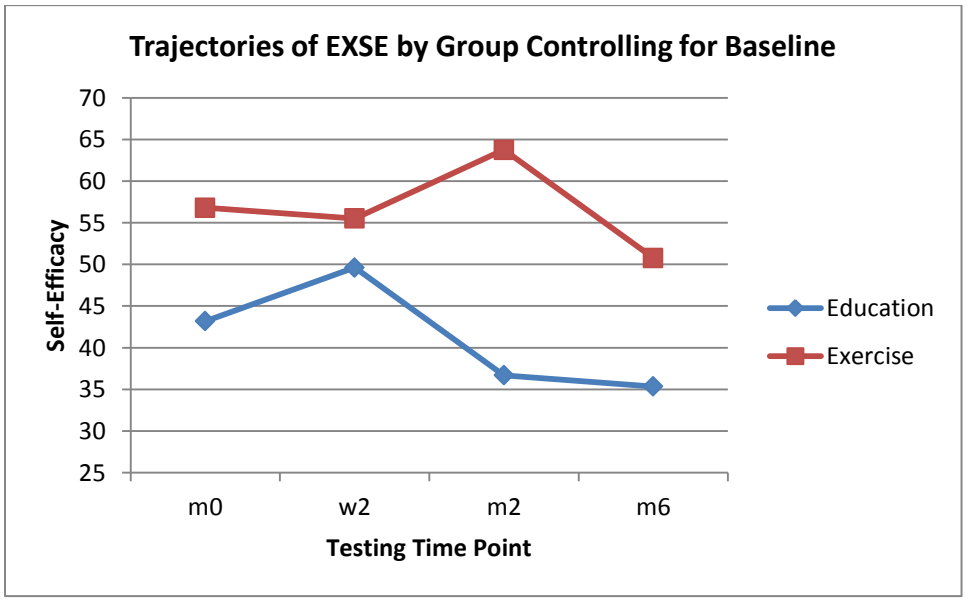
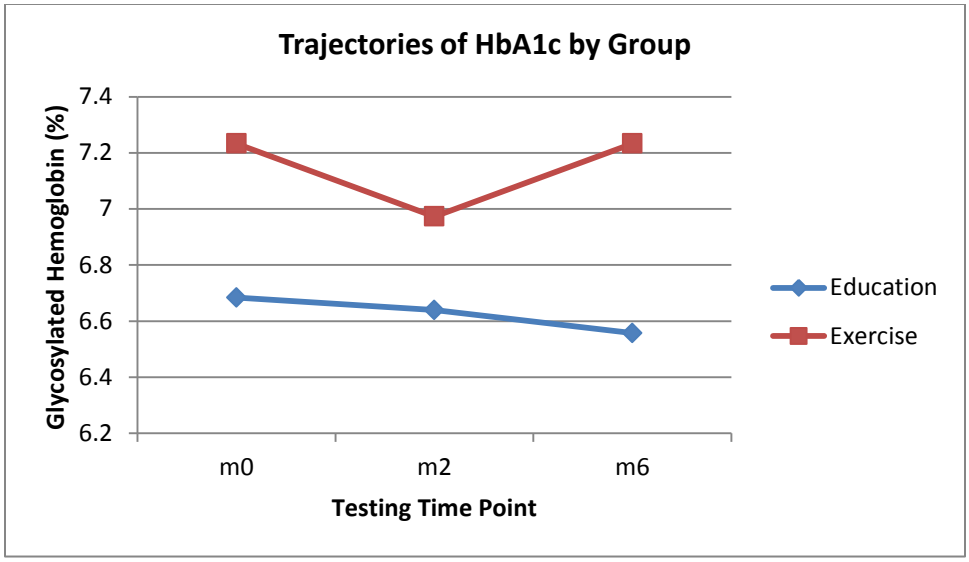


Figure 10. Trajectories of glycosylated hemoglobin by group



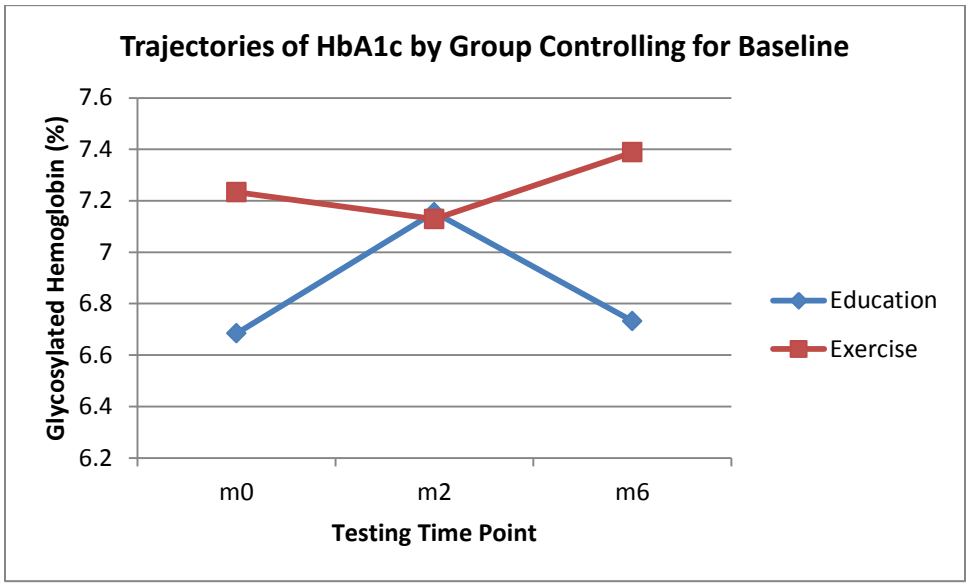


Figure 11. Trajectories of Fasting Blood Glucose by Group

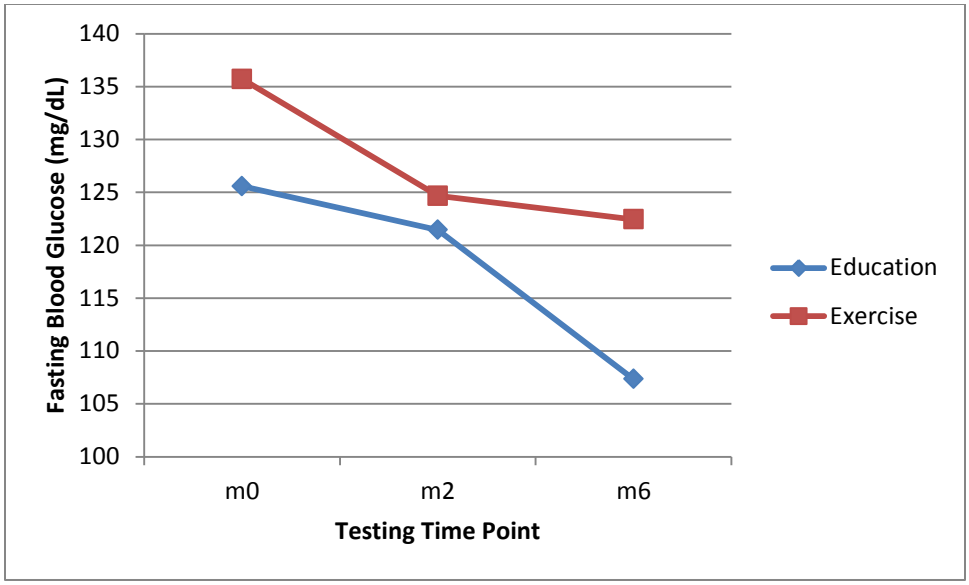


Figure 12. Trajectories of Moderate-to-Vigorous Physical Activity by Group